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14. ABSTRACT
The purpose of the study was to provide a review of current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, and to assess the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality, while reducing sustainment requirements. From those reviews, the study team recommended the Army (1) conduct operational effectiveness analyses on system-of system concepts; (2) assess heavy vertical lift options; (3) revise the unmanned aerial system road map; and (4) develop manned/unmanned teaming systems.

15. SUBJECT TERMS
Army aviation, vertical lift, manned/unmanned teaming (MUM-T)

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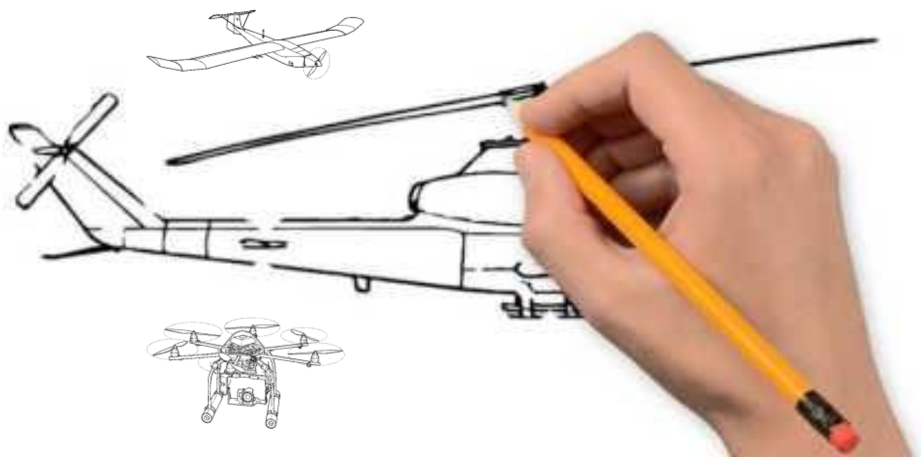
Army Science Board
Fiscal Year 2015 Study

Army Science and Technology for Army Aviation 2025-2040

Final Report
February 2016



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EXECUTIVE SUMMARY - THE FUTURE OF ARMY AVIATION

This study was conducted by the Army Science Board (ASB) from January 2015 – October 2015 under the sponsorship of the HQDA G-3/5/7. The reference task title for the study is "Army Science and Technology for Army Aviation 2025-2040." As stated in the Terms of Reference (TOR) signed by the Secretary of the Army, the overarching objective of the study was to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025 – 2040 timeframe that will:

- Increase Army Aviation's expeditionary capabilities to support full-spectrum military operations, and
- Reduce its sustainment tails and logistics footprint.

Fundamental to making any recommendations on S&T enhancements for Army Aviation in 2025-2040 is the assumption that the character of warfare is changing and that the role of Army Aviation in this future must also change. The character of warfare is clearly evolving rapidly, evidenced by significant new threats to Army Aviation and indications that they will continue to grow. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS), which can be easily procured through commercial outlets.

The study team believes that the most promising opportunity to overcome these threats is a "system of systems" approach involving formations of manned vertical lift aircraft and unmanned aircraft systems tied together by manned-unmanned teaming (MUM-T). The technical performance required of the "aviation system" and the elements needed in these various operational scenarios must be determined. Thus, a specific starting point and our most important recommendation, is to perform operational effective analyses that will inform the details of needed technical systems that incorporate emerging technologies and quantify requirements for these systems.

The study team identified the more general technology trends and opportunities that should enable viable solution options for addressing the threat space, as well as improve safety, lethality, and survivability for the manned-platforms, while reducing life cycle cost. Viewing Army Aviation as a complex system, a "system of systems," requires enhancements and development of the various systems and components. An enhanced investment in Army Aviation Research and Development (R&D), with greater focus on evolving capabilities in several areas to include UAS and autonomy, will enable a new "Army aviation system" to be fielded in 2025-2040 and provide the S&T foundation for a rapid evolution of capability beyond 2040. We also noted that the current timelines for development and fielding of several new systems are driven more by funding availability than by technology limits. Increased focus aviation R&D will permit rapid development of truly "integrated" systems, leading to more rapid fielding of the needed formations of systems.

The Army Science Board had previously conducted three recent studies that provided relevant background for global trends in science and technology (S&T) and that identified the opportunities and challenges that are likely to face the Army in this time period (2025-2040):

1. “The Strategic Direction for Army Science and Technology” (2012)
2. “Army Science and Technology Essential Core Competencies” (2013)
3. “Decisive Army Strategic and Expeditionary Maneuver” (2014)

The ASB has recognized that as the global rate of change of S&T continues to increase, the technical and operational challenges and opportunities for the conduct of warfare in this period should also increase.

In conducting the study, the team made more than 30 visits to Government and industry organizations and reviewed over 500 documents. Visits with Mr. John Shipley (Army Special Operations Aviation), LTG Kevin Mangum (Deputy Commanding General, TRADOC), MG Michael Lundy (Commanding General, US Army Aviation Center of Excellence) and others in the intelligence community, were particularly illuminating for the team in that they provided specific information concerning the severity and complexity of both current and recognized future threats to Army Aviation. These threats (and potential opportunities) include those from cyber, lasers, the electromagnetic spectrum, UAS swarms, and MANPADS. While the threats identified are important to Joint and coalition aviation in general, the lower-altitude environment of Army Aviation is particularly problematic for portions of the potential threat space.

The extensive input gained through all of these visits and interactions provided the study team the background to form a consensus and clear “working assumption” that the character of war is changing rapidly and the proliferation of relatively low-cost and evolving threats will only increase and become more uncertain by 2025 and beyond. Thus, the current military aviation environment and the rapid evolution of adversary options provided the study team a contextual input that went beyond technologies that may be useful in individual aviation vehicles and/or weapons systems.

The study team found that the Future Vertical Lift (FVL) family of systems represents the current planning for future of Army Aviation manned (and optionally manned) vertical lift systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). It was noted that the cost of the heavy lift option may preclude it from being a viable option. The team found that several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T. Current Army Aviation UAS assets consist of the Raven, Puma, Shadow, and Gray Eagle systems. These systems are all fixed-wing, have limited autonomy and limited MUM-T capability, and are essentially dedicated to one or two mission areas.

The study team organized the findings and recommendations of the study into three categories/recommendation sections:

- Context: Character of Warfare in 2025 and Role of Army Aviation
- Addressing Capability Gaps: Development and Acquisition
- S&T Portfolio: Innovation and Game Changers

As stated earlier, the most important recommendation is to perform operational effective analyses that will inform the details of needed technical systems that incorporate emerging technologies and quantify requirements for these systems. Following from this recommendation, the study team suggests that the envisioned aviation fighting “system” would generally have more than one vehicle/system participating, and has used the phrase “system of systems” to describe the approach. Also in the first category/recommendation section, the study team recommended that, if heavy lift is determined to be cost-prohibitive, it should not be assumed to be available in analyses, wargames, and exercises.

The future Army Aviation capability must include an expanded use of UAS assets that are, in most cases, viewed as “complements” and “extensions” to manned aviation. Enablers for near-term options would require work in UASs, mission systems, aviation systems integration, and the development of testbeds to develop and validate technical and operational concepts. The study team also recognized the importance of cost and speed in the introduction, acquisition and operation of more capable future Army Aviation “systems.” Following from these general observations, in the second category/recommendation section, the study team found that the capability gaps to enable viable options in the 2025-2040 time period would very likely need increased emphasis in the following areas:

- Unmanned Aircraft System (UAS) Vehicles
- Modernization of Legacy Rotorcraft Systems
- Future Vertical Lift (FVL) Acquisition with Speed and Simplicity
- Aviation Mission Systems
- Aviation Systems Integration and Testbed

The need for a strong aviation S&T portfolio to enable new options in this rapidly changing 21st century environment is also needed. In the third category/recommendation section, the study team found that due to the dynamic nature of the global technology environment, there exists a needed for increased emphasis in the following areas:

- Advanced and Disruptive Systems S&T
- S&T Investment Strategy

A summary of the key recommendations for each of the three categories/recommendation sections follows. Note that these recommendations are not in priority order but rather in hierarchical order beginning with system of system recommendations, followed by technology building blocks, and then by preparing to address emerging technology through S&T investment. The team believes that all nine recommendations are essential to the future of Army aviation. The first recommendation, to perform system of systems operational analyses must be acted on first because it will provide details to define the remaining recommendations. It is anticipated that the analyses will indicate that some areas require more improvement than others and hence are more urgent and require great investment. For example, UAS development will most likely require greater investment. The emphasis on early integration of these building block areas is also essential for the "Future Army Aviation system of systems" to be optimized and effective in the field.

Recommendations for Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses: The ASB recommends that TRADOC conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army Aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets, and enhanced lethality of DE weapons. These analyses must include the development of CONOPS and architectures for the most cost-effective concepts. As mentioned before, this is the most important recommendation. Army aviation must move away from the platform-centric approach currently employed to that of a system of systems. The significant advantages to Army Aviation of such an approach for survivability and lethality with its corresponding great potential cost advantages must be embraced moving forward. The results of these systems of systems operational effectiveness analyses are critical in guiding the path forward for Recommendations 3 – 6.

2. Affordability of Heavy Vertical Lift: The ASB recommends that TRADOC assess interim and future heavy vertical lift options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend the road ahead. If the development of heavy vertical lift capabilities proves to be cost-prohibitive, alternatives must be considered (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS). If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

Recommendations for Addressing Capability Gaps: Development and Acquisitions

3. UAS Vehicles: The ASB recommends that ASA(ALT) revise UAS Roadmap to expand both near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). It should be noted that both the Navy and Air Force have much more mature visions for UAS than the Army.

4. Modernization of Legacy Rotorcraft Systems: The ASB recommends that ASA(ALT) continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles (e.g., ITEP/FATE engines, DVE capabilities, and greater MUM-T) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

5. Future Vertical Lift Acquisition with Speed and Simplicity: The ASB recommends that ASA(ALT) develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system and industry's substantial investment should be leveraged to get the next-generation rotorcraft in service as soon as possible. It is key that requirements creep be kept to a minimum using successful acquisition examples such as the F-16 program as a guide, i.e., keep the initial designs simple but incorporate modularity for future updates.

6. Aviation Mission Systems: The ASB recommends that AMRDEC/ADD expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1). Needs include additional advanced mission systems (e.g., offensive and defensive DE capabilities) and open systems architectures.

7. Aviation Systems Integration and Testbed: The ASB recommends that RDECOM build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comms, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations"). The ASB also recommends that RDECOM, building on Recommendation 1 with relevant content from Recommendations 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR-TD), prototype, surrogate, and operational systems.

Recommendations for S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T: The ASB recommends that RDECOM, in order to address expanding complex threats and opportunities, develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success. The ASB also recommends that ASA(ALT) include in the Army's S&T portfolio leap-ahead technologies (e.g., counter-DE, counter-UAS, advanced materials).

9. S&T Investment Strategy: The ASB recommends that AMRDEC/ADD continue active participation in VAATE and RAMPED engine development. The ASB further recommends that RDECOM explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to the DARPA construct). Lastly the ASB recommends that ASA(ALT), after exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

Summary

In order to overcome the complex threats that Army aviation will face in the future, it is essential to adopt a system of systems approach. As noted above, the team's recommendation to perform

"System of Systems Operational Effectiveness Analyses" is the most critical of all the recommendations because it informs the remaining recommendations. Recognizing that the technical and operational details will follow from these analyses, the ASB strongly recommends that Army Aviation move away from the current platform-centric approach to focus on the systems of systems approach. Due to the distributed nature of systems of systems approaches, there are compelling advantages to Army Aviation for flexibility, safety, survivability and lethality with significant potential cost advantages.

A complete list of the ASB findings and recommendations is provided in the following table. As already pointed out, all nine recommendations are essential to the future of Army aviation. The first recommendation, to perform system of systems operational analyses must be acted on first because it will provide details to inform the remaining recommendations

Topic	Findings	Recommendations
Context: Character of War in 2025 and Role of Army Aviation		
1. System of Systems Operational Effectiveness Analyses	Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details) Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs. A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.	**TRADOC:** Conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/ unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets and enhanced lethality of DE. Develop CONOPS and architectures for the most cost effective concepts.
2. Affordability of Heavy Vertical Lift	Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept." However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040. Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.	**TRADOC:** Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead • If development of HVL is cost prohibitive, consider alternatives. • If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.
Addressing Capability Gaps: Development and Acquisition		
3. UAS Vehicles	The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions. DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army aviation. New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.	**ASA(ALT):** Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)
4. Modernization of Legacy Rotorcraft Systems	Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment. Within the current limited budget, Army aviation S&T is investing in technologies that apply to both legacy and future manned systems. These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.	**ASA(ALT):** Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).
5. FVL Acquisition with Speed and Simplicity	JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM. The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system. The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows. The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.	**ASA(ALT):** Develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

Topic	Findings	Recommendations
6. Aviation Mission Systems	Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks. RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking. Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS). Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed. Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed. DoD provides singular modeling and wind tunnel capabilities (NASA Ames)	**AMRDEC/ADD:** <u>Expand mission system technology development,</u> currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)
7. Aviation Systems Integration and Testbed	Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing. Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE). Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.	**RDECOM:** <u>Build the components of an integrated "survivable" system</u> (MUM-T, attritable assets, secure comm, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations"). **RDECOM:** Building on Recommendation 1 and Sections 2-6, <u>develop an aviation integration testbed</u> for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.
S&T Portfolio: Innovation and Game Changers		
8. Advanced and Disruptive Systems S&T	Army aviation is at a crossroad of challenge and opportunity. • The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber). • The opportunity: technology is emerging that enables significant improvement in aviation capabilities. Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise. There is relevant work in other Services, DARPA, and NASA that should be leveraged.	**RDECOM:** To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success. **ASA(ALT):** Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)
9. S&T Investment Strategy	Based on findings in Sections 1-8, the capabilities of Army Aviation <u>S&T must evolve rapidly</u> (e.g., need to expand UAS and autonomy activity); thus the <u>level of S&T activity must expand</u> beyond the manned aviation S&T portfolio, which is currently well managed. Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms. Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.	**AMRDEC/ADD:** <u>Continue active participation</u> in VAATE and RAMPED engine development. **RDECOM:** <u>Explore innovative mechanisms</u> for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct). **ASA(ALT):** After exploring leveraging opportunities with other R&D activities, <u>advocate more funding</u> for Aviation S&T.

1 INTRODUCTION

In January 2015, the Secretary of the Army requested the Army Science Board to conduct a comprehensive study of Army Aviation focused on science and technology important to the continuing development of advanced capabilities for Army Aviation assets. The G3/5/7 was identified as the study sponsor. As stated in the Terms of Reference (TOR) for the study, provided in Appendix A, the study objective was "to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025-2040 timeframe that will increase Army Aviation's expeditionary capabilities to support full-spectrum military operations and reduce its sustainment tails and logistics footprint."

The TOR specified three tasks for the study team:

1. Review current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, modernization plans and ongoing developments, as well as relevant Force 2025 and Beyond Campaign activities.
2. Address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply. Include, but not necessarily be limited to, the following key focus areas for improvement:
    a. Near-zero maintenance platforms and systems,
    b. Exploitation of unmanned aircraft systems,
    c. Meeting the challenges of emerging threats, and
    d. Enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.
3. Determine the feasibility and risks associated with each of the findings and recommendations.

This ASB report describes the conduct of the study; discusses Army Aviation challenges, needs, and opportunities; reviews ongoing aviation S&T activities in numerous areas; and provides numerous findings and recommendations important to enhancing future Army Aviation capabilities. A comprehensive briefing describing the study in detail was completed and approved by a vote of all members of the ASB in July 2015. A summary briefing of study findings and recommendations was presented to the Secretary of the Army, the Chief of Staff of the Army, and other senior Army officials in October 2015.

1.1 Study Team, Visits, and Literature Survey

The study team established to address these tasks, identified in Appendix B, included ASB members with significant technical expertise and experience in a wide range of disciplines:

- Physics
- Materials science
- Energy
- Fluid dynamics
- Technology transition
- Signal processing
- Robotics
- Electronics

- Aerospace engineering
- Electrical engineering
- Mechanical engineering
- Nuclear engineering
- Strategic planning
- Systems engineering and integration
- R&D management
- Directed energy weapons
- Command and control
- Optical communications
- Armor/anti-armor technology
- Helicopter systems
- Weapons systems
- Military aviation operations

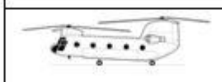
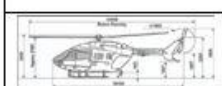
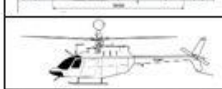
To obtain the comprehensive and detailed information required to address the specified tasks, members of the study team made over 30 visits to Army and other organizations actively involved in the development of advanced capabilities pertinent to Army Aviation. These organizations are listed below:

- Army
    - Aviation and Missile Research Development and Engineering Center (AMRDEC)
        - Aviation Development Directorate (ADD)
        - Weapons Development and Integration Directorate (WDI)
    - PEO Aviation and Program Managers (AS, CH, UH, AAH, ASH, NSRWA, FW, UAS)
    - US Army Aviation Center of Excellence (USAACE)
    - US Army Aeromedical Research Laboratory (USAARL)
    - Combat Readiness/Safety Center
    - TRADOC Capability Managers (UAS, Lift)
    - Communications Electronics Research Development and Engineering Center (CERDEC)
        - Night Vision & Electronic Sensors Directorate (NVESD)
        - Intelligence and Information Warfare Directorate (I2WD)
    - Army Research Laboratory (ARL)
    - Army Special Operations Aviation (ARSOA)
    - Operational Support Airlift Agency (OSAA)
    - Vertical Lift Research Center of Excellence (Georgia Tech)
- Other Services
    - Navy – Naval Air Systems Command (NAVAIR)
    - Air Force – Air Force Research Laboratory (AFRL)
- Joint/DoD
    - Future Vertical Lift IPTs
    - Defense Advanced Research Projects Agency (DARPA)
- Other
    - NASA Headquarters
    - NASA Langley Research Center
    - NASA Ames Research Center
    - Army Aviation Association of America (Quad-A)
    - Vertical Lift Consortium
    - Industry organizations

Lines of inquiry associated with these visits are summarized in Appendix C. Information and observations responsive to Task 1 are provided in Appendices D, E, F, G, H, and I. Study findings, observations, and recommendations associated with Tasks 2 and 3 are presented in Sections 3 and 4 below. Appendix J provides the final briefing presented in July 2015. Appendix K provides a list of acronyms and abbreviations used in this report. Numerous documents collected and reviewed in conducting the study are cited in the Bibliography in Appendix L.

1.2 Current Army Aviation Platforms

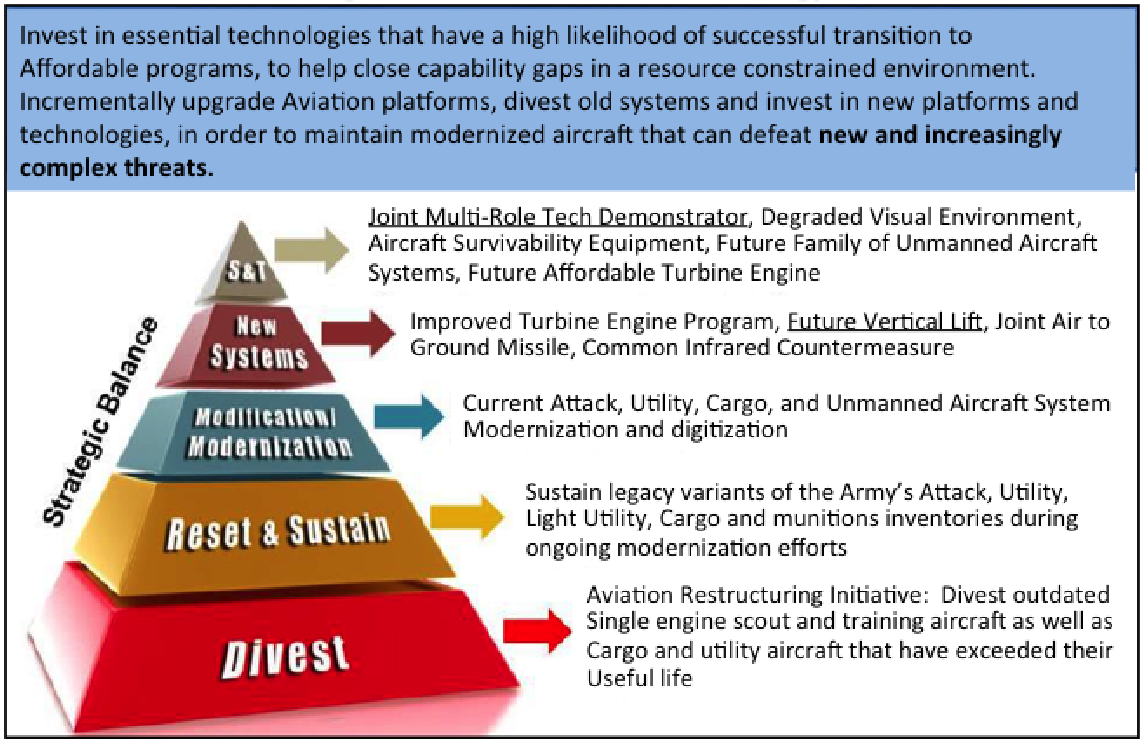
The Army currently employs the six rotary wing aircraft, as described in Figure 1-1. The Little Bird (also called the "Killer Egg") is used only by SOCOM. The Kiowa observation helicopter is being retired. The Lakota is only approved for use in CONUS, where it is used as a trainer. The remaining three aircraft, the Chinook, Black Hawk, and Apache, form the core of Army Aviation. Note that these platforms were designed more than 30 years ago and are expected to remain in the fleet through 2060.

Army Legacy Rotorcraft	Name / Designator	Role	IOC/ Retire?	Status	Max Takeoff	Max Load	Cruise Speed/ Range	Developer (inventory)
	Chinook CH-47D/F	Cargo	1962 / 2060	Block II available in 2020	50,000 lb	28,000 lb	130 kt / 400 nm	Boeing (503)
	Black Hawk UH-60	Utility	1979 / 2060	Upgrades + ARI transfer*	23,500 lb	2,640 lb int, 9,000 lb ext	159 kt / 640 nm	Sikorsky (1,565)
	Apache AH-64	Attack	1986 / 2060	Upgrades + ARI transfer*	23,000 lb		143 kt / 257 nm	Boeing (756)
	Lakota UH-72	Trainer, CONUS only	2007 / ???	ARI use for training	7,900 lb	3,950 lb	133 kt / 370 nm	Eurocopter (307)
	Kiowa OH-58D	Observa-tion	1969 / soon	ARI retire*	5,500 lb	1,700 lb	110 kt / 140 nm	Bell (618)
	Little Bird A/MH-6	SOF	1980 / ???		3,100 lb	1,500 lb (6 pax)	135 kt / 232 nm	McDonnell Douglas / Boeing (47)

* ARI – Aviation Restructuring Initiative

Figure 1-1 Army Legacy Rotorcraft

Figure 1-2 illustrates the Army Aviation Modernization Strategy. S&T efforts sit at the top of the pyramid; they include the Joint Multi-Role Technology Demonstration (JMR-TD) and Degraded Visual Environment (DVE) activities, which are the largest Army Aviation S&T efforts. As Army Aviation S&T efforts mature over time, emerging advances are incorporated into new systems, such as JMR-TD technologies that will inform the Future Vertical Lift (FVL) program. Other new systems, such as the Improved Turbine Engine Program (ITEP) engines, are part of the modernization of select legacy systems. Still other emerging technologies support sustainment of legacy systems. Finally, at the base of the pyramid outdated systems are divested.



Source: Army Equipment Modernization Strategy, March 2015 (Annex E – Aviation) - G8

Figure 1-2. Army Aviation Modernization Strategy

The Aviation Restructuring Initiative (ARI) is a five-year plan to reduce Army Aviation costs while addressing fleet obsolescence and sustainment issues. It was approved by the CSA in December 2013, with the first execution order issued in April 2014. The ARI calls for the Army to:

- Cut three of the 13 active-duty combat aviation brigades; Army Reserve component would retain 12 aviation brigades – 10 in the National Guard and two in the Army Reserve.
- Retire OH-58 Kiowa Warriors and TH-67 trainers (both single-engine aircraft).
- Use Apache to fill Kiowa's reconnaissance and scout role.
- Replace TH-67 training helicopters with dual-engine LUH-72 Lakotas.
- Move Apaches from the Guard to active Army and, in turn, provide the Guard with UH-60 Black Hawks. This plan has been controversial for the Guard.
- Have 20 Apache battalions in active components.

The National Guard has proposed retaining more crews and units, but some units would only be partially equipped. Cost Assessment and Program Evaluation (CAPE) analysis indicates that the Army plan is not sized for prolonged stability operations. The National Guard alternative costs $89M to $176M annually plus a one-time cost difference of approximately $500M. Congress postponed the transfer of Apaches until FY2016 and established a National Commission on the Future of the US Army that will conduct two studies: (1) the structure of the Army and policy assumptions related to the size and force mixture of the Army, and (2) transfer of Apaches from the Guard to the active Army. The ARI will not be discussed further in this report.

The Army also has a fleet of over 339 fixed wing aircraft, all commercial derivative aircraft. The fleet includes three categories of aircraft:

- Special Electronic Mission Aircraft (SEMA):
  - EO-5 Dash 7, RC-12 Huron (Guardrail), B-300 Beechcraft
- Transport Aircraft:
  - Warfighting Combatant Commanders: C-12 Beechcraft, C-26 Metroliner, UC-35 Cessna
  - Executive Transport: C-20 Gulfstream, C-37 Gulfstream
- Mission Support Aircraft:
  - RDT&E: C-208, T-34
  - USMA Flight Laboratory: CE-182
  - Golden Knights Parachute Team: UV-18 Twin Otter, C-31

In addition to its rotary wing and fixed wing aircraft, Army Aviation also employs four unmanned aircraft systems (UAS), described in Figure 1-3. Raven and Puma are both small hand-launched UAS used for ISR missions. The Shadow is a larger UAS, also used for ISR missions. Gray Eagle is a much larger UAS that can carry Hellfire missiles as well as an ISR pod. Only Shadow and Gray Eagle can be controlled by manned aircraft (Apache AH-64E) in Manned-Unmanned Teaming (MUM-T) operations.

Legacy Army UAS	Name / Designator	Role	IOC	Payload	Max Takeoff	Cruise Speed/ Endurance	Developer (# built)
	Raven RQ-11A/B	Small UAV, Hand launch	1999	ISR	4 lb	30 kt / 1-1.5 hrs	AeroVironment (19,000+)
	Puma RQ-20A		2007	ISR	13.5 lb	45 kt max / 2 hrs	AeroVironment (1,000+)
	Shadow RQ-7A/B	Short Range Tactical	2002	ISR	375 lb	70 kt / 9 hrs	AAI Corp (~500+)
	Gray Eagle MQ-1C	Predator Upgrade	2009	ISR pod / Hellfire	3,600 lb	150 kt max/ 30 hrs	General Atomics (~100)

Figure 1-3. Army Legacy Unmanned Aircraft Systems

2 ARMY AVIATION CHALLENGES, CAPABILITY NEEDS AND SYSTEM CONCEPTS

2.1 Challenges Facing Army Aviation

Army Aviation is facing multiple challenges that require new ways of thinking regarding the character of Joint warfare in 2025 and beyond, as well as how Army Aviation should be employed to be most effective in the integrated Joint battlespace of the future.

2.1.1 Survivability

Among the most pressing of these challenges is the growth and proliferation of advanced threats that place Army Aviation assets at high risk. The Capstone Concept for Joint Operations: Joint Force 2020[1] highlights the issue of the proliferation of sophisticated threats and the need for new Concepts of Operation (CONOPS) for countering the threats and maintaining overmatch:

> "Our nation and Armed Forces are transitioning from a decade of war to a future that presents us with a security paradox. While the world is trending toward greater stability overall, ***destructive technologies are available to a wider and more disparate range of adversaries***. As a result, the world is potentially more dangerous than ever before. ***New concepts of operation are needed*** to address the security paradox we face."
>
> "The diffusion of advanced technology in the global economy means that middleweight militaries and non-state actors can now muster weaponry once available only to superpowers. The ***proliferation*** of cyber and space weapons, precision munitions, ballistic missiles, and anti-access and area denial capabilities ***will grant more adversaries the ability to inflict devastating losses***. These threats place our access to the global commons at risk, target our forces as they deploy to the operational area, and can even threaten forces at their points of origin. Meanwhile, adversaries continue to explore asymmetric ways to employ both crude and advanced technology to exploit U.S. vulnerabilities. Consequently, the capability advantage that U.S. forces have had over many potential adversaries may narrow in the future. Adversaries will not only have more advanced capabilities in every domain. More of them will have the ability to simultaneously fight across multiple domains."

Figure 2-1 illustrates some of the threats facing Army Aviation today and in future conflicts. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS), which can be easily procured through commercial outlets. Currently, the most worrisome threat is posed by man-portable air defense systems (MANPADS) such as the systems shown in Figure 2-2. Some of these threats are discussed in a classified annex to this report.

[1] Joint Chiefs of Staff, *Capstone Concept for Joint Operations: Joint Force 2020*, Washington, DC, 10 Sept 2012, http://www.defenseinnovationmarketplace.mil/resources/JV2020_Capstone.pdf.

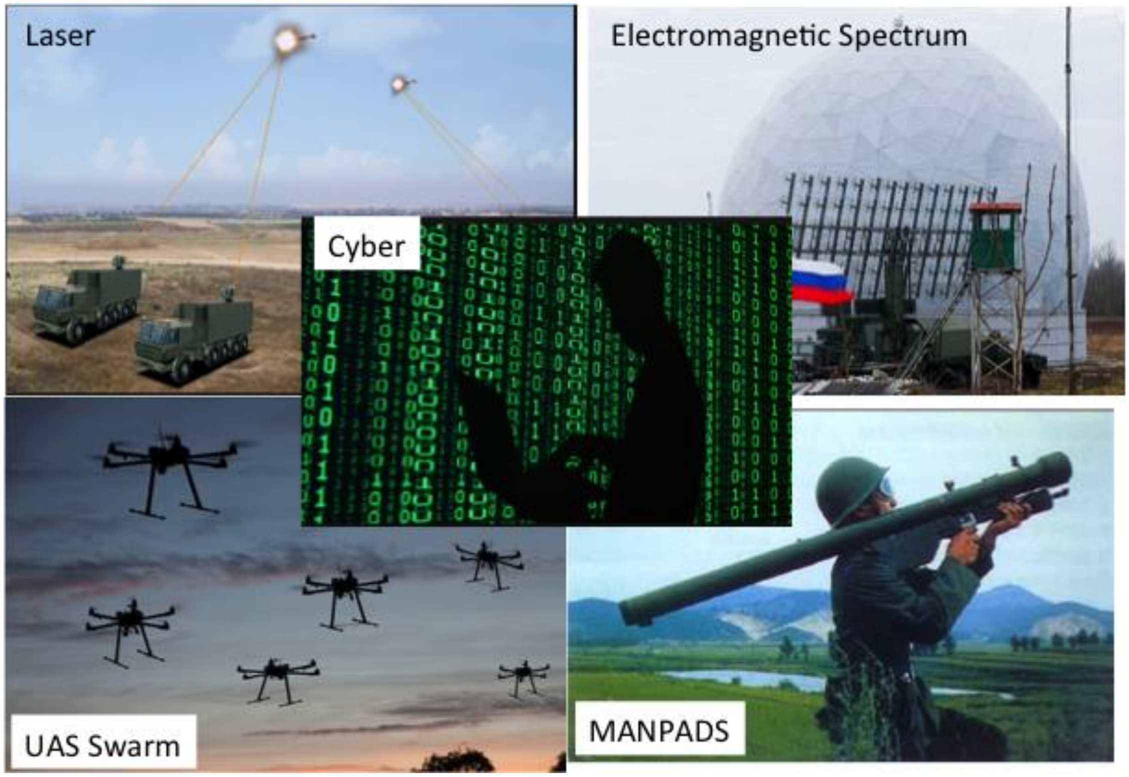


Figure 2-1. Complex Threats and Opportunities

1967	Generation 1 (SA-7, HN-5, REDEYE) • Hot Metal Tracker • Poor Airframe Response • No Counter-Countermeasure (IRCCM)
1976	Generation 2 (SA-14, SA-16) • Plume Tracker – All Aspect • Poor to Good Airframe Response • No IRCCM
1981	Generation 3 (Stinger, QW-1, SA-18, SA-24) • Plume Tracker – All Aspect • Good Airframe Response • IRCCM – Countermeasure Capable (Flare Rejection)
1990	Generation 4 (Stinger RMP, Mistral II, FN-6, SA-29) • Re-programmable Processors • Advanced IRCCM
2014	Generation 5 (Stinger Block 2, QW-4) • Infrared Imaging Seeker • Digital Processing • Reprogrammable IRCCM

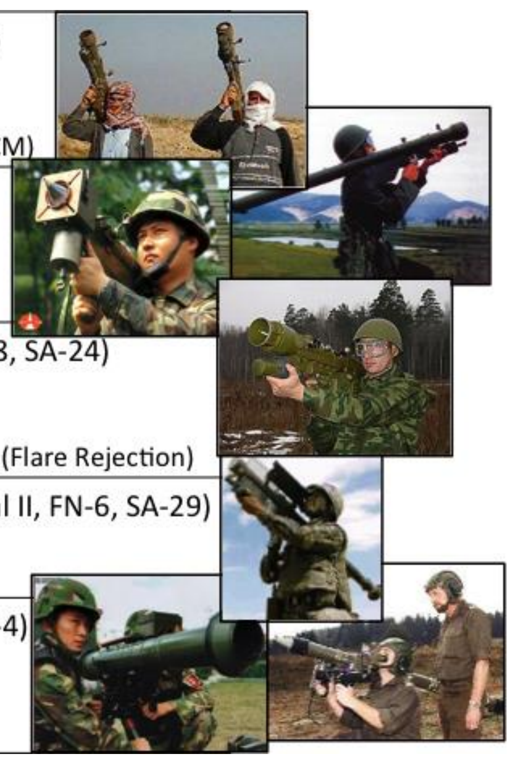


Figure 2-2. Generations of IR MANPADS

2.1.2 Vertical Lift for Expeditionary and Operational Maneuver

A second pressing challenge is the inability of current Army Aviation systems to satisfy the need for strategic, expeditionary, and operational maneuver of dispersed mechanized forces in austere areas of operation in the face of capable anti-access and area denial (A2/AD) threats in future conflicts. The recently released Army Operating Concept[2] highlights the need for operational maneuver and sustainment to point-of-need for dispersed forces:

- Respond Globally: "When called upon, globally responsive combined arms teams ***maneuver from multiple locations*** and domains to present multiple dilemmas to the enemy,..."
- Conduct Joint Combined Arms Operations: "Joint combined arms operations create multiple dilemmas for the enemy. Army forces ***achieve surprise*** through ***maneuver across strategic distances,*** and arrival at unexpected locations. Army forces have the mobility, protection, and firepower necessary to strike the enemy from unexpected directions. In high ***anti-access and area denial*** environments, ***dispersion*** allows future army forces to evade enemy attacks, deceive the enemy, and achieve surprise."
- Sustain High Tempo Operations: "Army sustainment units integrate efforts with the Joint Force to ensure unimpeded sustainment flows across the land, air, and maritime domains. These units provide supplies and services to the ***point of need..***."

The burden on Army vertical lift assets for providing supplies on the battlefield was increased as a consequence of the decision to retire the C-23 Sherpa cargo plane and transfer the fixed-wing supply mission to the Air Force. Army commanders who need small quantities of supplies must either wait until there is an available, scheduled AF C-130 or send a rotary wing vehicle to transport the material. This has led to increased workloads (and hence increased maintenance) for rotary wing aircraft.

Current Army Aviation assets cannot provide the heavy vertical lift (20-30 stons; see section 2.2) needed for expeditionary and operational maneuver of ***mechanized*** dispersed forces. This need was detailed in the 2014 Army Unified Quest exercises,[3] the 2014 ASB study on Strategic and Expeditionary Maneuver,[4] and the 2012 Army-Marine Corp Concept:[5]

- ***Unified Quest 2014***: "Self-deployable Army future vertical lift capabilities and joint shallow draft systems must be capability development options. These efforts are essential to future strategic, operational, and tactical maneuver and enable dispersed forces to maintain mutually supporting functions."

---

[2] TRADOC Pamphlet 525-3-1, "*The U.S. Army Operating Concept: Win in a Complex World*, 2020-2040," 31 October 2014, http://www.tradoc.army.mil/tpubs/pams/tp525-3-1.pdf.

[3] Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 March 2015, http://www.arcic.army.mil/Library/documents.aspx.

[4] Army Science Board, *ASB FY2014 Summer Study - Decisive Army Strategic and Expeditionary Maneuver, July 2014*.

[5] Army Capabilities Integration Center and Marine Corps Combat Development Command, *Gaining and Maintaining Access: An Army-Marine Corps Concept*, March 2012.

- ***2014 ASB study on Decisive Army Strategic and Expeditionary Maneuver***: "Vertical lift is an essential enabler for synchronized distributed interdependent maneuver via unpredictable entry points."
- **2012 Gaining and Maintaining Access: An Army-Marine Corps Concept**: *"*Vertical maneuver of *mounted* forces provides the means to rapidly gain positional advantage over the enemy creating and magnifying the effects of surprise."

The challenge for the Army is the lack of funding necessary to develop and procure a heavy vertical lift system to satisfy these needs. Army Aviation funding is discussed in Section 2.1.5.

2.1.3 Aging Legacy Rotorcraft Systems and Future Vertical Lift

Army Aviation is continually faced with the challenge of trying to achieve an optimal balance of its R&D investments committed to modernizing/upgrading legacy rotorcraft platforms and to developing new systems that offer expanded performance capabilities and reduced sustainment compared to current systems. This balancing challenge is exasperated by the limited funding allocated to aviation efforts within the Army S&T portfolio (see section 2.1.5).

The Future Vertical Lift (FVL) Family of Systems (FoS) represents the future of Army Aviation manned (and optionally manned) rotorcraft systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). Therefore, if the program were to follow normal DoD acquisition processes for an ACAT I Major Acquisition Program and the Planning, Programming, Budgeting and Execution (PPBE) processes, an Initial Operating Capability (IOC) for FVL would not be expected until the mid-2030s. Once IOC has been achieved, at historical Army Aviation procurement funding levels it will take roughly 30-40 years to replace the legacy platforms.

It is expected, therefore, that legacy rotorcraft systems (AH-64, CH-47 and UH-60), which are all 1960-1970 vintage designs, will remain deployed until at least 2060. This century-long platform life would be rivaled only by the B-52 bomber, which has been re-purposed from its original mission to extend its utility. The noted Army rotorcraft platforms have undergone several upgrades over their lifetimes. At least one more major upgrade to these systems, however, will be required beyond those currently in progress or funded within the POM for them to remain operationally effective against evolving threats, as reflected in the FVL first aircraft timeline shown in Figure 2-3. Fortunately, several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

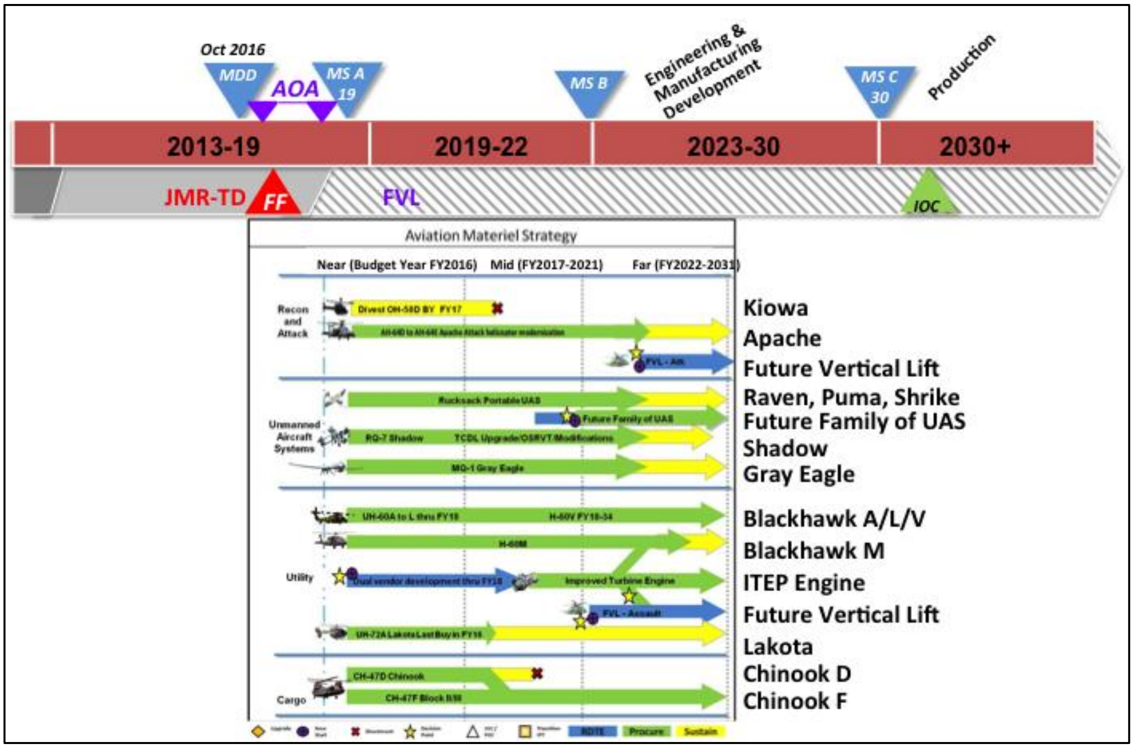
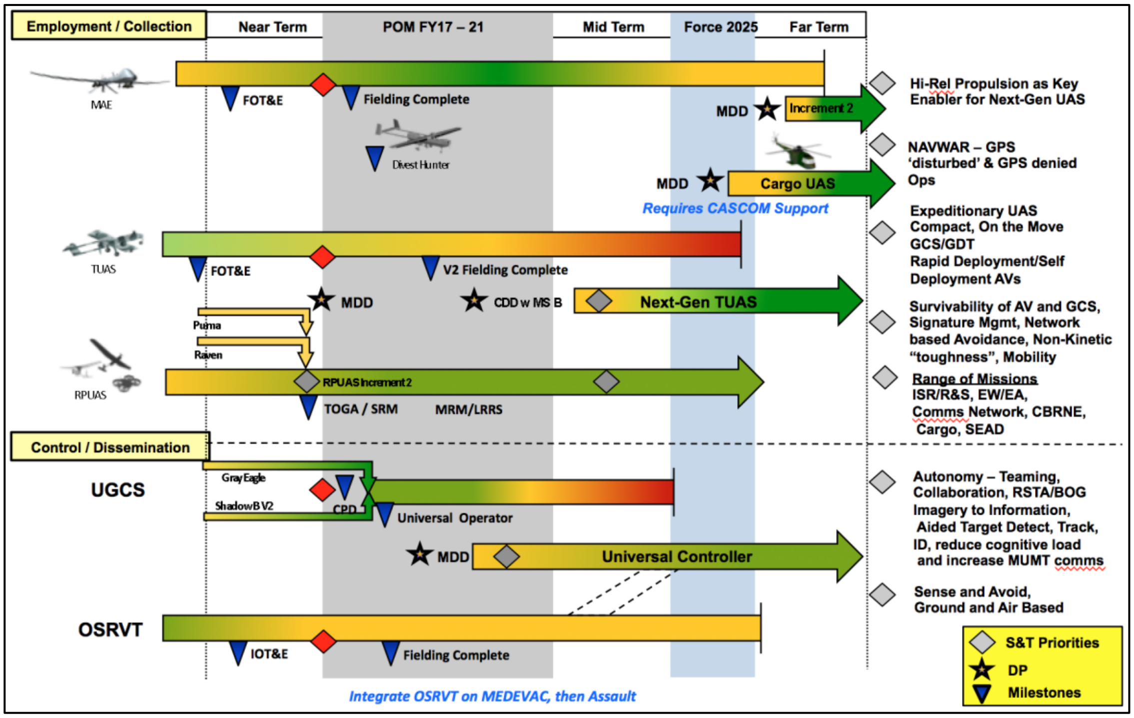


Figure 2-3. FVL – First Aircraft Timeline

2.1.4 Unmanned Aircraft Systems (UAS) and Manned-Unmanned Teaming (MUM-T)

Current Army Aviation UAS assets consist of the Raven, Puma, Shadow, and Gray Eagle systems. These systems are all fixed-wing, have limited autonomy and limited MUM-T capability, and are essentially dedicated to a single mission (ISR, although Gray Eagle can carry Hellfire missiles in addition to ISR payloads). Currently, the AH-64E has the capability to control the Shadow and Gray Eagle flight path and payload (but not takeoff or landing). Although the Army UAS Roadmap[6] cites plans to upgrade these platforms and eventually to develop replacements for some of them (see Figure 2-4), it lacks a clear vision for expanding the use of UAS as complements and extensions to manned aviation, rather than simply as ISR systems. Expanding the mission set and increasing autonomy for UAS are identified as far-term objectives in the roadmap, but very limited funding is currently allocated to achieving these objectives. Army S&T programs to advance manned-unmanned collaboration and UAS autonomy are discussed in Section 3.3.

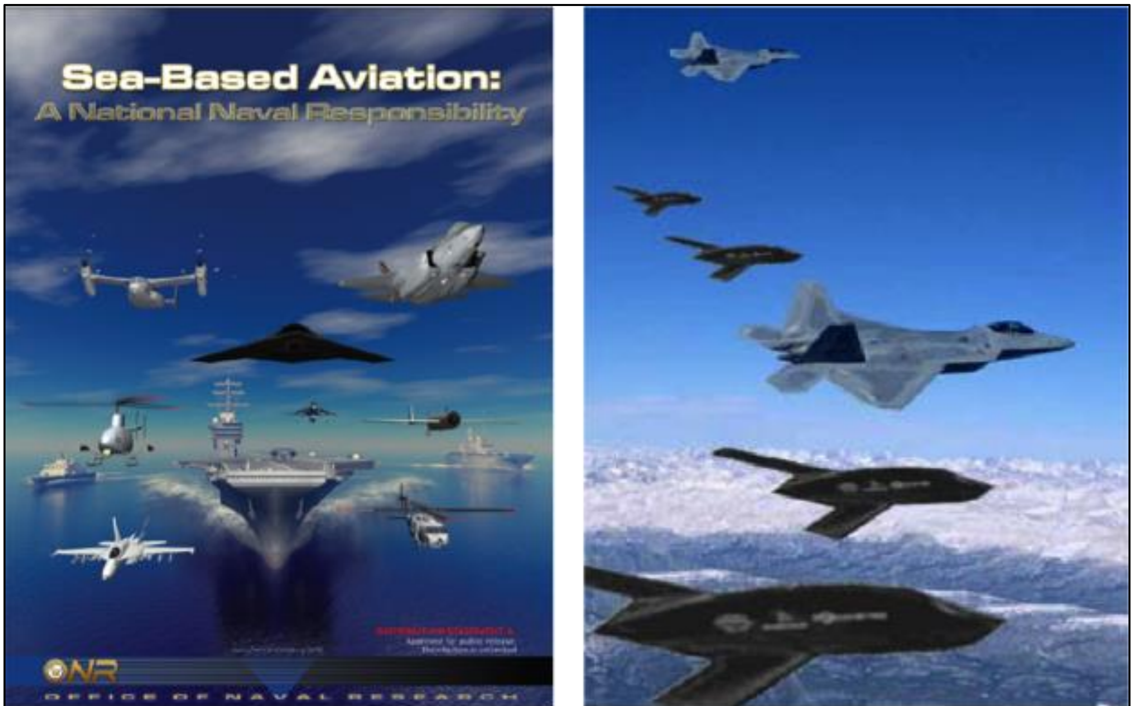
[6] US Army UAS Center of Excellence, *"Eyes of the Army," U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .



Source: UAS S&T Priorities Briefing by PM-UAS 30 Mar 2015

Figure 2-4. UAS S&T Priorities

In contrast to the Army Aviation UAS roadmap, the USAF and USN/USMC have bold visions for expanded roles/missions for UAS and greater use of collaborative MUM-T, as reflected in Figure 2-5. In the center of the USN "Sea Based Aviation" document cover page are three UAS systems: the Unmanned Carrier Launch Airborne Surveillance and Strike System (UCLASS) in the middle, the MQ-8 Fire Scout unmanned helicopter to the left of UCLASS and the RQ-21 version of the Scan Eagle UAS to the right. The UCLASS is intended to perform deep strike missions currently conducted by manned fighter/attack aircraft. The Secretary of the Navy has indicated that the F-35C should be the USN's last manned fighter jet. The RQ-21 is a modular design that allows a wide variety of mission payloads, providing multi-mission flexibility. Among the payloads either deployed or in development are SIGINT, EW, Communications Relay, SAR/GMTI, real-time targeting and wide-area persistent surveillance. The USAF illustrates the Unmanned Combat Air Vehicle (UCAV) flying in close formation with the F-22, providing "wingman" capabilities utilizing autonomous operations under supervised control of the manned fighter.



SECNAV: "F-35C should be Navy's last manned strike jet" 4/16/15

Figure 2-5. The Navy and Air Force Have Visions for UAS

The need for similar unmanned capabilities within Army Aviation was highlighted by Unified Quest 2014,[7] which evaluated the key roles that UAS can and should play in the future Army integrated battlespace:

> **"Unmanned** air and ground platforms that enhance soldier decision-making and action with self-planning, self-navigation, and mission execution capabilities will have significant potential to change the future battlefield. ***The Army must develop concepts of employment for future autonomous and unmanned systems in the near-term to integrate them efficiently into the force in the far-term (2030-2040)."***

The rapidly advancing technologies associated with UAS, autonomous systems, and MUM-T should be viewed as a significant opportunity for Army Aviation to better integrate collaborative manned-unmanned capabilities into its future force. However, a major challenge in expanding the Army Aviation UAS portfolio, increasing MUM-T capabilities, and meeting this UQ vision is the small percentage of Army S&T funding allocated to UAS (see Section 2.1.5).

[7] Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 Mar 2015, http://www.arcic.army.mil/Library/documents.aspx.

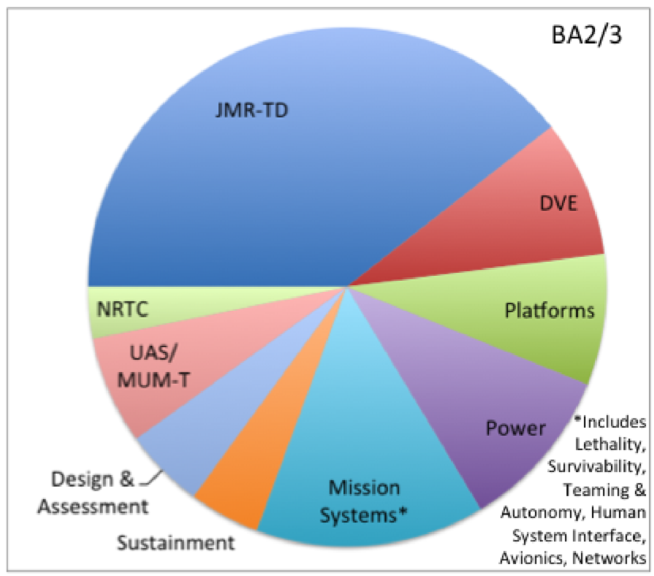
2.1.5 Army Aviation Funding

Army Aviation must somehow meet all of the challenges detailed above within an S&T budget that is only about 8% of Army S&T funding (Figure 2-6). The lack of a robust budget is perhaps its most significant challenge that is outside of the Army Aviation community control.

The Army is the lead Service for DoD rotorcraft systems and technologies. The other Services are dependent on a robust Army Aviation S&T program. The Army should, of course, leverage technology developments by the other Services, NASA, and DARPA, as well as commercial industry initiatives. NASA rotorcraft spending, however, is down to $20M in FY2016, and DARPA investments in rotorcraft technology developments, while currently robust, are variable.

- Army FY16 Requested TOA is $126B
- Procurement Total is $16.1B
- Aviation Procurement is $5.7B (34% of Procurement)
- Army S&T* Total is $1.77B
- Army Aviation S&T* is $144M (8% of S&T)
- DoD Rotorcraft S&T* is $207M (Army is lead Service with 64% of total)
- NASA Rotorcraft Funding is $20M

*BA2/3



Current level and focus of funding is inadequate to meet challenges

Figure 2-6. Meeting Future Challenges Demands a Robust Aviation Portfolio

Within the Army Aviation S&T budget, a healthy portion is devoted to the JMR-TD program, which provides the validation of aerodynamic and aeromechanics technologies for FVL. This Army investment is more than matched by industry participants in the program. The two JMR demonstrator aircraft are sized to match the medium class FVL, which will ultimately replace the AH-64 and UH-60 legacy systems. There is little current investment, however, to support an ultra-heavy class of vehicle that would satisfy the heavy vertical lift capabilities required for maneuver of mechanized dispersed forces. Also, and particularly vexing, is the small allocation of Army Aviation S&T to UAS and MUM-T. It is difficult to imagine how Army Aviation will satisfy its challenges and validated capability needs (discussed in Section 2.2) within these budget constraints.

2.2 Army Aviation Capability Needs and Gaps

The Army Aviation capability needs and gaps to meet these challenges are well documented in JROC-validated Capability Based Assessments (CBAs) and Initial Capability Documents (ICDs) developed through the JCIDS process (Figure 2-7).

- System/Platform
  - Future Vertical Lift (FVL) CBA, 21 Jun 10
  - FVL Family of Systems (FoS) ICD, 8 Apr 13
  - Joint Future Vertical Lift (JFVL) ICD, Oct 09
  - Joint Heavy Lift (JHL) ICD, 12 Oct 07
  - Unmanned Systems ICD, 14 May 10
- Aircraft Survivability
  - Aircraft Survivability CBA, 6 Jan 09
  - Degraded Visual Environment CBA, 21 Jul 09
  - Aircraft Survivability ICD, 6 Oct 11

Figure 2-7. Army Aviation Capability Needs & Gaps Emanate from Validated JCIDs Documents

The capability needs and gaps for FVL are documented in the JROC approved FVL FoS CBA and ICD. Capability objectives in the FVL ICD document gaps associated with many of the challenges discussed previously in Section 2.1:

- **Operational and Tactical Vertical Movement:** The future force requires VTOL Aviation to support the operational and tactical movement of forces to achieve a position of advantage with respect to enemy forces. Vertical movement requires aerial delivery and airborne operations to move supplies, and insert/extract personnel and equipment across the range of military operations.
- **Destroy, Neutralize or Suppress Enemy Targets:** FVL should employ a variety of future and legacy weapons systems against a wide array of existing and emerging threats.
- **Air Reconnaissance, Surveillance and Target Acquisition:** Future systems should conduct the full range of intelligence, reconnaissance, surveillance and target acquisition missions. FVL FoS platforms will maintain surveillance of areas to detect, identify, prioritize and designate targets; increase responsiveness; and exploit the capabilities of interoperability between manned and unmanned systems.
- **Execute Network-Enabled Command, Control and Reporting:** FVL platforms should execute network-enabled C2 and reporting for SA, fires, JF integration and collaboration.
- **Aviation Sustainment, Maintenance and Supply Activities:** Future systems should increase platform availability, reliability, sustainability, maintainability, energy efficiency / reduced fuel consumption and logistics footprint.
- **Safety and Survivability of Aircraft and Personnel:** Protect the aircraft, aircrew and passengers departing controlled flight, from impacting hazards, effects of enemy

weapons, and onboard aircraft fire or crash damage. Safety shall not be compromised by Hazards of Electromagnetic Radiation to ordnance, fuel, personnel, EMI, or ESD.

The FVL ICD translated these capability needs into performance objectives for three classes of vehicles: Light, Medium and Heavy (see Figure 2-8). As indicated, among the key performance objectives is higher speed than conventional helicopters can achieve, which drives the aircraft configuration choices to compound/hybrid or tilt-rotor concepts. JMR-TD is developing and testing demonstrators for these advanced concepts. The distinguishing feature between the FVL classes is payload, with the light configured to carry a SOCOM team (6 passengers), the medium to carry a squad (12-24 passengers) and the heavy a platoon (33-53 passengers).

Capability	**Performance Goal***	**Performance Value**
Worldwide Performance	Operate 90+% in Critical Regions	HOGE at 6 kft and 95°F
Combat Radius	Operate Across Army Division AO	424 km
Cruise Speed	Transit Army Division AO Within 1 Hour	170 – 300 kts
Internal Payload	L: 6 Passengers M: Squad and up to 20K H: Equivalent to USMC CH-53K	L: 2.5K+ lbs M: 5K – 20K lbs H: 20K – 30K lbs
External Performance	L: Equal to Internal M: M777 Howitzer and JLTV H: Equivalent to USMC CH-53K	L: 2.5K+ lbs M: 13K – 23K H: 30K
Passengers	L: SOCOM Team M: Squad H: Platoon	L: 6 M: 13 – 24 H: 33 – 53
Self Deployment	Transit Longest Leg of Pacific	3889 km

* L – Light, M – Medium, H - Heavy

Figure 2-8. FVL ICD Performance Objectives

A fourth class of vehicle that is discussed in the FVL ICD is the ultra-heavy class, which is capable of moving mechanized forces, including medium-weight armored vehicles. The capability needs for this class are documented in the Joint Future Vertical Lift (JFVL) ICD as well as in the Joint Heavy Lift (JHL) ICD. The capability needs in the JFVL ICD address the challenge of strategic and operational maneuver of dispersed mechanized forces in austere areas of operation:

- Transport forces over strategic and operational distances to points of need/effect bypassing traditional PODs;
- Conduct precision air delivery of supplies over strategic and operational distances with required velocity;
- Operate into austere, short, unimproved landing areas with limited infrastructure;
- Perform operational maneuver with medium weight armored vehicles and personnel;

- Reposition medium weight armored vehicles and personnel by airlift;
- Minimize RSOI.

Critical capability needs for the Joint Future Vertical Lift system include a payload capability of 20-36 stons, the ability to self-deploy from CONUS to theatre, a mission radius with payload of 250-1000 nm, and a speed that allows for in-flight refueling.

The Aircraft Survivability ICD combines the aircraft survivability CBA with the Degraded Visual Environment (DVE) CBA. It addresses, therefore, both the need for survivability over the full spectrum of conflict against capable threats and the need for aviation assets to conduct operations in degraded visual environments. Requirements extracted from the ICD include:

- The future modular force will leverage aviation that is capable of deploying worldwide to conduct full spectrum operations and survive against lethal threats in a wide variety of physical environments and weather conditions that severely degrade pilot visibility.
- Survivable aviation assets will enable joint forces to conduct operational maneuver from strategic distances; deploy through multiple, unimproved points of entry, forcibly if necessary; and overwhelm hostile anti-access capabilities to rapidly bring and apply combat power to the enemy.
- These units will arrive in the AO with the ability to conduct immediate, simultaneous, distributed and continuous combined arms operations throughout the operational environment.

2.3 System Concepts to Meet the Challenges and Satisfy the Capability Needs

The challenges and capability needs for Army Aviation tend to group into three categories:

1. Survivability of aviation assets against proliferated capable threats,
2. Reliance on 1970 vintage legacy platforms beyond 2025-2040 until the advanced performance capabilities of FVL can be fully deployed, and
3. Vertical maneuver of dispersed mechanized forces required to implement the Army CONOPS.

Moreover, it is imperative to address these challenges within a budget-constrained environment and a relatively meager allocation of Army S&T funds to Army Aviation. System concepts and/or affordable solutions are required for each of these challenges to provide focus for Army Aviation S&T investments.

With respect to the first category, the current approach to survivability of Army Aviation systems is based on a traditional multi-layered approach centered on the platform, depicted in Figure 2-9 . The outer layer involves systems and techniques to avoid detection by a threat system, the next layer to avoid engagement by the threat, and so on. ROSAS, cited in the figure, is an AMRDEC Route Optimization for Survivability Against Sensors effort that seeks to demonstrate a real-time route planning system to avoid pop-up threats; it is intended to provide new capabilities for several of the protection layers. This layered “onion” approach has served well in the past. Next-generation threats and their proliferation, however, call into question how much longer this platform-centric approach can remain effective. On the one hand, it is not clear that the layering will provide adequate survivability against the advanced threats. Further, this platform-centric approach requires that all of the functionality of the "onion" (including threat detection and warning systems, countermeasure systems, signature management systems, active and passive protection systems, etc.) be integrated into a single platform. This approach results in a very high cost asset, which produces a very low ratio of threat kill cost to blue force loss cost. This cost ratio may place onerous limitations on the blue force commander on how and when to deploy aviation assets.

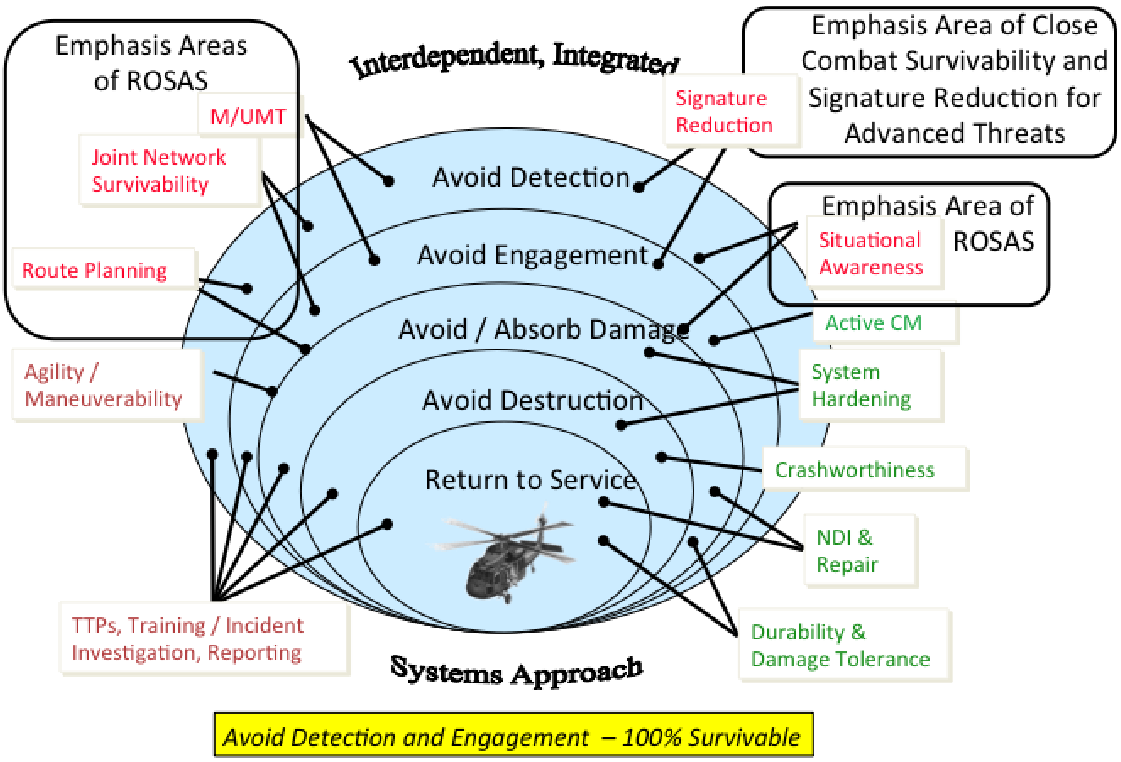


Figure 2-9 AMRDEC Total Survivability Paradigm – Platform-Centric

One approach to solving this platform-centric dilemma involves a system-of-systems (SoS) concept, which effectively adds another layer to the "onion" outside the platform itself, as illustrated in Figure 2-10. A limited number of elements of the SoS concept are already being implemented by means of the fusion of off-board information with on-board data and the recent upgrade of AH-64 to include Level 4 MUM-T capability with Shadow. However, a more robust vision for the future that takes fuller advantage of collaboration between manned and unmanned systems (similar to the USAF and USN/USMC visions illustrated earlier in Figure 2-5) is required to drive SoS solutions that fully exploit the synergy of unmanned systems operating in collaboration with the manned platform at the center of the "onion." Supervised semi-autonomous UAS can provide another layer important to survivability.

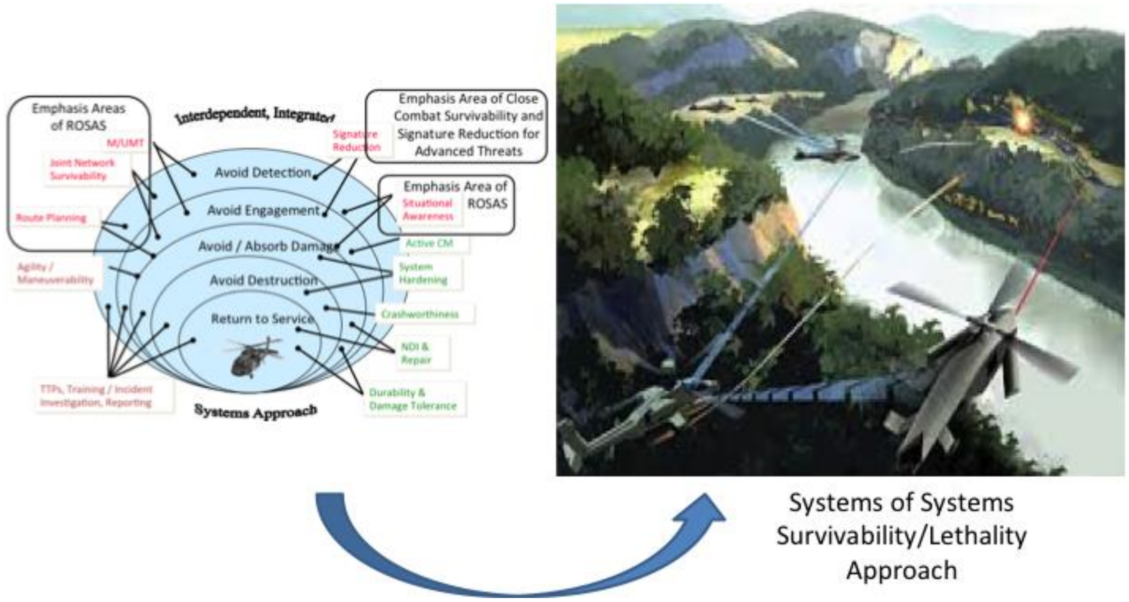


Figure 2-10 Total Survivability from a System-of-Systems Perspective

A top-level SoS concept for this outer layer of the "onion" is illustrated in Figure 2-11. In this concept, the manned aircraft serves as the mission supervisor, but much of the functionality to prosecute the mission is distributed onto UAS systems, which operate autonomously unless directed by the mission supervisor. Distributing the functionality improves mission and survivability and effectiveness in two ways. First, it greatly complicates threat response and adds a layer around the manned asset that the threat must defeat. Secondly, it reduces the cost of the manned asset, thereby reducing the ratio of cost of potential blue force asset loss to threat cost. This concept is discussed in more detail in Section 4.3. The UAS cost must, of course, be added to the overall blue force formation cost. However, in many cases the UAS may be of sufficiently low cost to be considered to be "attritable."

The second challenge category involves reliance on aging legacy rotorcraft systems until the Army can afford to make FVL a POR, develop the FVL aircraft, conduct OT&E, and gradually retire the earlier models as FVL variants are procured. As discussed previously, the current FVL schedule, which is driven by funding constraints as well as technology maturation, does not lead to an IOC of the *first FVL variant* (most likely the FVL-Medium replacement for either the AH-64 or UH-60) until the mid-2030 timeframe. After IOC, within anticipated procurement budget constraints, it will take a decade or two to replace the legacy system. It must be emphasized that this schedule applies only to the first FVL version. Funding constraints will limit development, testing, and procurement of the second and third variants to later timeframes.

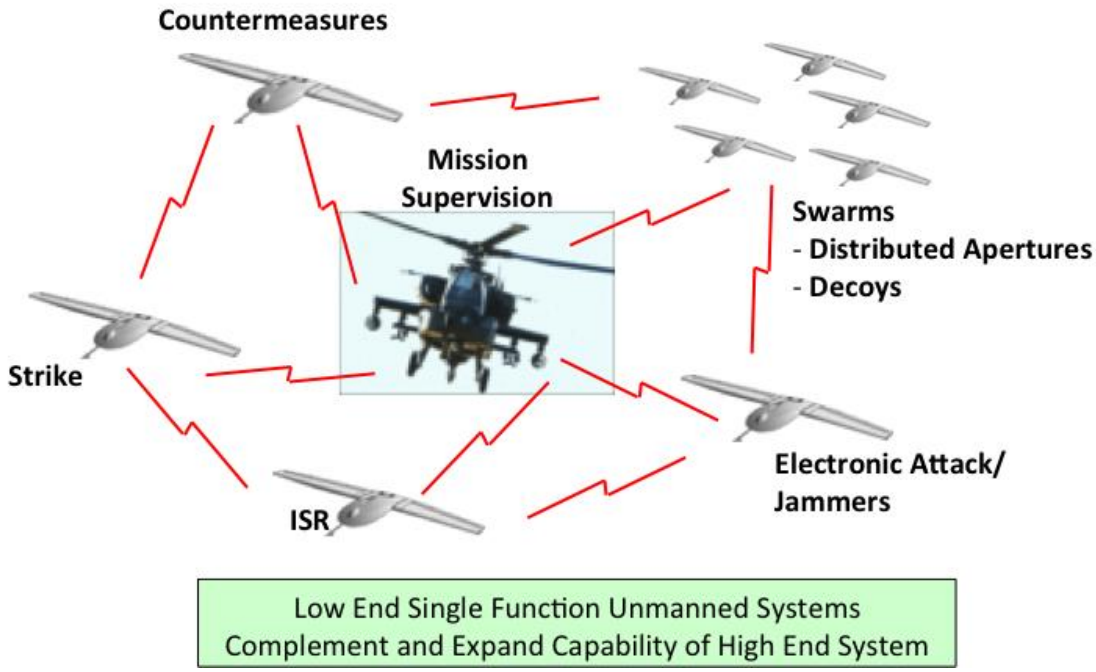


Figure 2-11 Distributed Functionality Collaborative System-of-Systems Concept

Acceleration of the FVL program would seem to provide some obvious benefits toward mitigating this issue. However, three roadblocks stand in the way of program acceleration: funding constraints, acquisition processes, and technology maturity.

Achieving affordability of FVL aircraft is critical to dealing with limited funding. Affordability, in turn, is driven by requirements. As the only new Army Aviation program on the horizon, FVL will be pressured by the operations community to have system and performance requirements that satisfy every possible operational need. Lack of requirements discipline is one leading cause of acquisition program failure. FVL will be no exception if the requirements process is not tightly managed and constrained. An approved DoD acquisition process, known as evolutionary acquisition, could prove to be of great value in managing requirements growth and in accelerating the introduction of FVL into the inventory. Under this acquisition strategy, the operational and acquisition communities would agree on a set of objective performance requirements, but also concur on a more limited set of the objectives that could provide an effective early operational capability. Pre-planned capability upgrades leading to the full set of objective requirements would also be defined. Such an approach would help not only to manage requirements, but also to accelerate IOC for a limited capability set.

Such acceleration, however, is dependent on technology maturity. In addition to unrealistic requirements and/or requirements growth, unrealistic evaluations of technology maturity is an additional significant cause of acquisition program failure. Fortunately for FVL, due to major industry investment, the JMR-TD demonstration vehicles will have greater fidelity and be more representative of the FVL-Medium operational design than would normally be expected. Parallel investments in the FACE/JCA open system architecture could provide the technology basis for some acceleration of a Milestone B DAB. This option is discussed in more detail in section 4.5.

The third challenge category is the lack of an Army Aviation capability to provide the heavy vertical lift necessary to support maneuver of dispersed mechanized forces in austere areas of operation. Because of the investment required to develop and produce the FVL-Medium class of aircraft, simultaneously developing an ultra-heavy class is simply not within the TOA of Army Aviation for the foreseeable future. Interim solutions that partially meet the heavy lift requirement are the only fiscally realistic options available to the Army. Potential interim solutions are discussed in section 4.2.

While this discussion has focused on the challenges facing Army Aviation, it is worth noting that many of the same forces driving the challenges also open opportunities for advancing Army Aviation to win in a complex world. In particular, expanded roles and missions for UAS and the better integration and collaboration of manned and unmanned assets provide the capability for new/improved roles and missions for Army Aviation as the character of future warfare continues to evolve. The system-of-systems distributed functionality concept introduced earlier (Figure 2-11) opens multiple new options for Army Aviation to contribute to Joint force effectiveness in future conflicts. As just one example, Army Aviation could play a more significant role in two missions that are normally tasked only to USAF forces: air superiority and SEAD. In the case of air superiority, lethal UAS under supervisory control of either Army or USAF manned attack assets could support the attack of threat airfields. SEAD missions could be enhanced through use of collaborative functionality formations that utilize UAS as stand-in jammers. Other opportunities are clearly possible, but they are limited for the 2025-2040 timeframe by funding constraints, particularly limited budgets for UAS and MUM-T.

3 KEY INNOVATIVE TECHNOLOGIES: FOCUS AREAS FOR IMPROVEMENT

The study Terms of Reference requested that the team address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply. This section explores such innovative technologies.

It should be noted that these innovative technologies will be most effective when integrated with other technologies. For example the Degraded Visual Environments (DVE) effort involves integration of sensor technologies, cueing technologies, and flight control technologies. The integration of unmanned systems, manned-unmanned teaming, and manned platforms into a system-of-systems provides the most promising means for affordable mission effectiveness. Incorporating Joint capabilities into an overall operating concept will help to ensure maximal effectiveness of these systems.

3.1 Challenging Environments

3.1.1 Degraded Visual Environments

In recent years, Army Aviation operations have experienced a series of serious accidents, several fatal, in which helicopters were losing stability as they landed in sandy areas of Iraq and Afghanistan. In 2010, a DoD study[8] found:

> "During Operation Enduring Freedom and Operation Iraqi Freedom (OEF/OIF), there were 375 rotorcraft losses with 496 fatalities from October 2001 to September 2009. Mishaps accounted for 81 percent of all losses with combat losses (i.e., aircraft shootdowns) accounting for the remaining 19 percent; 73 percent of the fatalities occurred in a combat theater. … The combined mishap loss rate (both combat non-hostile and non-combat) was 2.71 losses per 100,000 flight hours, slightly exceeding the loss rate due to combat hostile action. The in-theater mishap loss rate was ten times worse, and the out-of-theater loss rate was four times worse than the Congressional and SECDEF goal of 0.5 mishaps per 100,000 flight hours. Loss of situational awareness and other human factors accounted for more than 79 percent of the losses of airframe and fatalities. The primary causal factors are controlled flight into terrain and brownout."

The problem was that as the helicopters approached the ground they generated a large cloud of dust that completely surrounded the aircraft, causing a condition called "brownout" that virtually blinded the pilot. The brownout caused the pilot to lose orientation, which could cause the helicopter to tilt as it came close to the ground, with the rotors striking the ground. The Army identified this condition, which they called Degraded Visual Environment (DVE), and expanded it

[8] Mark Couch (IDA) and Dennis Lindell (Joint Aircraft Survivability Office), "Study on Rotorcraft Safety and Survivability," presented at American Helicopter Society 66th Annual Forum, DTIC A547531, May 2010.

to include other environments that are visually degraded, as illustrated in Figure 3-1. Two of these environments are induced by the aircraft: brownout in dusty terrain and whiteout in snow-covered areas. Naturally occurring environments include smoke, sand/dust storms, fog, rain, clouds, snow, smog, night, and flat light. DVE mitigation became one of Army Aviation's three highest priority needs. In addition to safety considerations, a key objective of DVE capability development efforts is to enable commanders to conduct operations deliberately in DVE because they will have an advantage over the adversary.

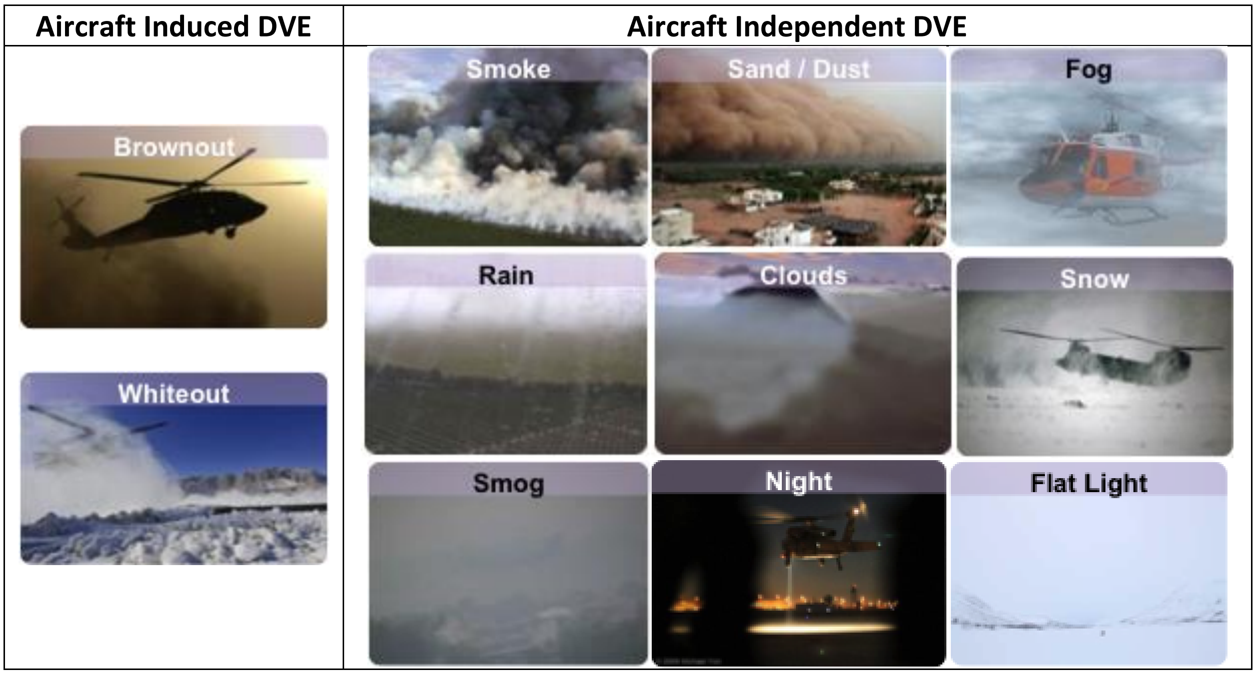


Figure 3-1. Degraded Visual Environments (2 + 9)

DVE mitigation is an RDECOM-wide effort based on integration of three technologies supported by complex computing. It includes work in three principal areas:

- Sensing – led by CERDEC
- Cueing – led by ARL (working with the US Army Aeromedical Research Lab - USAARL)
- Flight controls (to stabilize aircraft handling) - led by AMRDEC-ADD-AFDD

The threshold demonstration goals for the DVE program include rotorcraft pilotage capability in all limited visibility environments, all-around situational awareness, and the ability for multiple aircraft to cooperatively operate within DVE. The Army plans to test these goals by FY2020.

Limited Visibility Close to Ground – Sensor Development

Brownout is caused by the downdraft created by a helicopter as it lands over dust-covered ground. The cloud of dust creates a very opaque environment that makes it impossible for the pilot to see farther than one or two feet beyond the windshield of the cockpit. Sensors able to penetrate and generate images through the dust cloud are needed.

Sensor development work pertinent to DVE is being conducted at Fort Belvoir by the Night Vision and Electronic Systems Directorate (NVESD), an important element of CERDEC. NVESD technologists have identified a spectral “window” in the long-wavelength infrared (LWIR) band through which electromagnetic radiation can penetrate. Exploiting this phenomenon they have developed a sensor sensitive to that wavelength that is able to “see” through dust clouds. Unfortunately, the technology does not extend to other DVE conditions. Nevertheless, in theaters where dust is prevalent, the Army should seriously consider funding the integration of such sensors with the flight operating systems of its helicopters to enhance the pilot’s ability to ``see’’ through brownout.

CERDEC and Army Research Laboratory are also investigating the potential use of ladar and radar systems to overcome DVE. For example, high-resolution ladar images could be collected and stored prior to entering the landing zone and integrated with lower-resolution but obscurant-penetrating RF data to provide pilots with enhanced imagery and improved overall visibility.

Cueing and Flight Control Development

Cueing alternatives such as combinations of visual, aural, and tactical cues are being evaluated by the US Army Aeromedical Research Laboratory (USAARL) to optimize pilotage and aviator workload. USAARL is planning to assess DVE solutions in real-world environments, including high workload, reduced cues, fatigued aviators, and environmental stress. AMRDEC is exploring revised symbology sets such as the BrownOut Symbology System (BOSS), which attempts to present a single symbology strategy from start to finish of the approach, thereby eliminating the need to change pages or change scales.

AMRDEC is also developing modern control laws (MCLAWS) to improve flight control in legacy systems. These techniques can support additional automated flight modes, enabling capabilities such as terrain and obstacle avoidance and automated safe-landing modes. MCLAWS-2 is designed to provide an attitude-command/attitude-hold response type for improved handling in near-Earth operations at night and in poor weather. In-flight tests on the UH-60 demonstrated that both pilot workload and heading errors were reduced.

Addressing DVE in Future Integrated Programs

The RDECOM S&T effort is focused on developing an integrated DVE-Mitigation (DVE-M) system to be demonstrated in 2020. Component technologies will be demonstrated through FY2015. DVE-M goals include multi-ship networking for sharing of data and increased threat awareness from fused sensor data.

The study team considers the RDECOM DVE goals to be both appropriate and feasible. In addition, reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., enabling formations with UAS).

Just as adversaries have been able to acquire or develop night vision technology after US forces demonstrated the ability to "own the night," it must be anticipated that over time adversaries will also be able to operate in DVE. To maintain the advantage as long as possible, care must be taken to protect the technologies where feasible.

3.1.2 High/Hot Environments

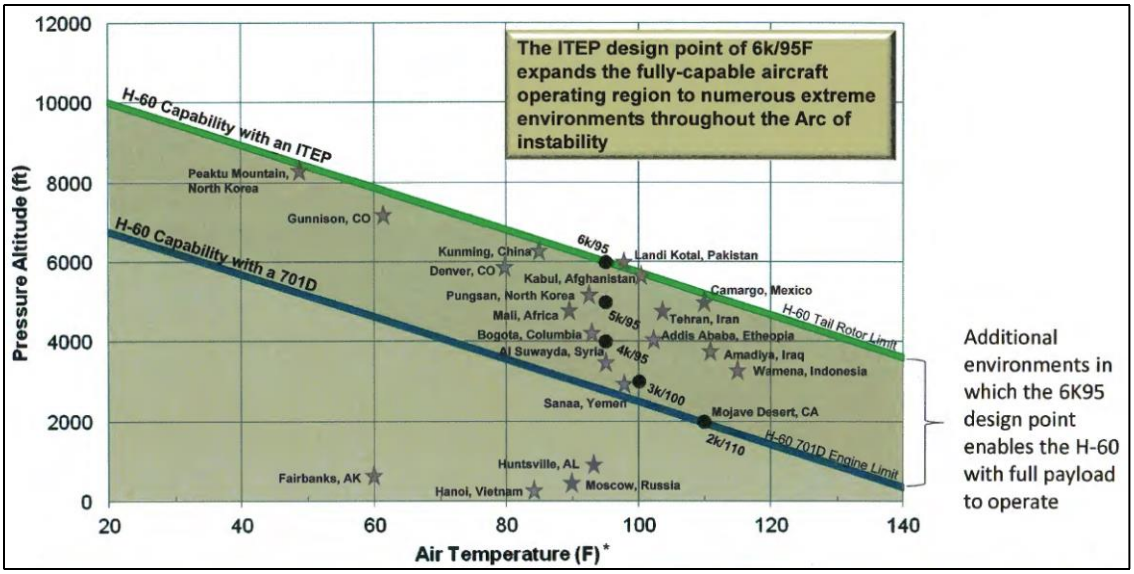
During the 1970s, the Army required helicopter engines that could transport an 11-person squad at 4,000 ft altitude at 95°F. Based on more recent experience, the requirement has been raised to carrying the same load to 6,000 ft altitude at 95°F.

Higher altitude or hotter temperatures, or both, lead to lower air density, which in turn reduces the lift generated by the rotors or wings. Reduced density also degrades the performance of the aircraft engines, exacerbating the problem. The primary short-term means for overcoming the effect of low density is to reduce aircraft weight, usually by reducing payload or fuel load. For example, during the Iraq and Afghanistan wars, Black Hawk helicopters were regularly flown at higher altitudes and hotter temperatures than their engines were designed to withstand. With underpowered engines in those conditions, each helicopter could carry only five soldiers — about half of an 11-person squad.[9]

Over the longer term, vehicle and engine designs can be modified to improve performance. The Advanced Affordable Turbine Engine program is working to develop an engine that is the same size as the legacy Black Hawk's General Electric T700 engine but 50% more powerful and 25% more fuel efficient. This technology will be incorporated into the Improved Technology Engine Program (ITEP) that will undergo a downselect in 2018 and the first engine test in 2021.

Figure 3-2 shows the nominal operating environments for a Black Hawk powered by the T700 engine and by the ITEP. Note that several locations of interest, such as cities in Afghanistan, Iraq, Iran and Columbia, cannot be reached using the T700 engine without reducing payload. The ITEP supports both Apache and Black Hawk modernization programs. The Future Affordable Turbine Engine (FATE) provides similar improvements for the Chinook. These advanced engines will also support the Future Vertical Lift program.

[9] Valerie Insinna, "Fuel Efficient Engine to Increase Range, Power of Army Helicopters," *National Defense Magazine*, NDIA, January 2014.



Source: Briefing by TCM Lift (COL Bentley), 11 June 2015.

Figure 3-2. Operating Environment for ITEP Engine

3.2 Condition-Based Maintenance and Near-Zero Maintenance Aircraft

Major advances in the development and use of aircraft health monitoring systems have been achieved over the last several decades. Such systems, now widely deployed on both commercial and military aircraft, offer significant potential for making maintenance operations a predictable and controllable activity. They enable the development and implementation of condition-based maintenance (CBM) practices that offer significant benefits in various areas compared to traditional corrective, preventative, and phased maintenance approaches. CBM is a maintenance process based on the known condition of various system components rather than a phased/scheduled inspection, repair, and replacement process. It involves monitoring the health and usage of components using sensors of various types to provide a rational basis for predicting individual component failure and establishing an appropriate timeline for repair and/or replacement actions. For fixed-wing aircraft, Boeing has successfully incorporated CBM into most of its aircraft systems, resulting in both reductions in maintenance costs and an overall increase in aircraft availability. CBM enablers have also been incorporated into numerous commercial and military rotary wing aircraft.

The Department of Defense has a longstanding commitment to implementation of CBM practices for a comprehensive range of defense systems, as reflected in establishment of its Condition Based Maintenance Plus (CBM+) Initiative in November 2002.[10] CBM+ is stated to be “an evolving set of maintenance capabilities focused on inserting technology into new and legacy systems that will improve supportability, lead to more efficient and effective business processes, and transform DoD’s maintenance environment.” It is intended to build on “the solid foundation of condition-based maintenance,” but it also includes a wide range of other maintenance and

[10] Department of Defense, “Condition-Based Maintenance Plus (CBM+): A DoD Initiative,” November 2014. http://www.rwappleton.com/downloads/CBMDODPublication.pdf.

logistics considerations. CBM+ is "condition-based maintenance enhanced by reliability analysis; it is routine predictive maintenance based on the evidence of need and forecasted by analyzing data collected through automated sensors and systems." Development and implementation of effective CBM+ practices are intended to contribute to improved weapon system and equipment performance, as well as lead to enhanced readiness, more efficient maintenance, reduced logistics footprints, and associated cost savings.

Stated policy key tenets for CBM+ include (1) need-driven, reliability-centered maintenance, (2) embedded diagnostics and prognostics, (3) automated maintenance information generation, (4) analysis-based reliability and sustainability process improvements, (5) integrated information systems responding to equipment condition and tasking, (6) smaller maintenance and support footprints, and (7) improved operational availability and performance. Cited examples of CBM+ enabling features include (1) sensors, embedded onboard or off-board (portable) equipment interfaced to a platform, together with software programs to facilitate analysis, (2) data collection, (3) maintenance information systems network for both up line reporting/recording and downline support, (4) information tools (interactive electronic technical manuals, portable maintenance aids, computers, etc.), (5) engineering analysis to identify trends and provide a dynamic maintenance plan, and (6) systems integration linking logistics and maintenance.[11] Development and implementation of CBM+ capabilities is clearly a complex process. An ultimate issue is whether, and how soon, it might lead to desired near-zero maintenance aircraft (ZMA) for Army Aviation.

Over the last several decades, the DoD and the Services have made major investments in the development of technological capabilities important to the continuing advance of CBM capabilities. Early major investments by the Army led to the development of integrated vehicle structural health monitoring capabilities such as the IVSHM system, developed by Goodyear for Army Aviation in 2002, and health and usage monitoring systems (HUMS), such as the system developed for the UH-60 Black Hawk.[12] HUMS capabilities have subsequently been integrated into most Army rotary wing aircraft (AH-64D, OH-58D, and CH-47D helicopters; all US Army Special Operations Aviation Command helicopters). HUMS is a sensor-based monitoring system that enables preventative maintenance by measuring the health and performance of mission-critical components. It has been cited as "the kind of environment that CBM+ is trying to establish."[13] By continuously monitoring vibration at numerous points throughout the drive train and pinpointing mechanical faults before they become catastrophic failures, HUMS provides actionable information that allows the military operators to anticipate mechanical failures and make anticipatory maintenance decisions.[14] Realized benefits include greater aircraft availability,

[11] "Condition-Based Maintenance Plus (CBM+): A DoD Initiative," op cit.

[12] MAJ Marc P. Gaguzis, "Effectiveness of Condition Based Maintenance in Army Aviation," MS Thesis, US Army Command and General Staff College, Fort Leavenworth, KS, 2009, http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA502155.

[13] "Condition-Based Maintenance Plus (CBM+): A DoD Initiative," op. cit.

[14] Honeywell, "HUMS Systems Keep the US Military Mission Ready," 3 January 2013, https://aerospace.honeywell.com/news/hums-systems-keep-the-us-military-mission-ready.

lower costs resulting from reductions in unplanned maintenance events, more optimal parts inventory management and logistics, and enhanced safety.

All of the Services have significant ongoing efforts to develop CBM+ capabilities, particularly for aviation systems. For the Army, those efforts are very comprehensive and extend across all of the principal RDT&E categories, as summarized in Appendix E - Army Aviation Efforts. Two major active Army efforts are the Autonomous Sustainment Technologies for Rotorcraft Operations (ASTRO) program and the Ultra Reliable Design program.[15,16] The ASTRO program is a jointly funded effort by industry and the Aviation Applied Technology Directorate of AMRDEC to develop and demonstrate technologies and methodologies enabling more efficient designs and reduce the maintenance burden for current and Future Vertical Lift (FVL) aircraft. Its principal focus is on advanced technologies for propulsion, structures, rotors, and drives. The objective of propulsion technology work is to demonstrate adaptive engine controls to optimize performance, component life, and maintenance schedule based on engine health. The structures technology effort seeks to develop technologies for assessing the structural integrity of a primarily composite airframe, verifying the integrity of composite repairs, and predicting remaining useful life. Rotors technology work is developing automated methods to sense rotor system track and balance and enable real-time adjustments in flight. Drive system technology activities include development of planetary gear failure detection and weight reduction technologies, culminating in an integrated transmission demonstration in FY2016.

The Army's Ultra-Reliable Design program will develop a set of tools, methodologies, and materials to apply ultra-reliability concepts to the design and operation of FVL aircraft. Ultra-reliability has been defined as an order of magnitude improvement in materiel reliability over the current standard, achieving higher availability while reducing life cycle costs and downtime associated with maintenance activities. The program will be executed in three phases:

- Phase 1 will assess materiel reliability of current Army aircraft in the Army fleet and key reliability drivers for future aircraft; identify and analyze effective design-for-reliability practices; identify current and future technology transition points applicable to FVL reliability; and recommend technology investments, reliability design criteria, and potential development or acquisition process changes required to achieve ultra-reliable rotorcraft design.
- Phase 2 will develop design tools, methodologies, and materials consistent with the findings of the Phase 1 assessment and applicable to the design of future aircraft.
- Phase 3 will develop and demonstrate modeling and simulation tools and components/ sub-systems to verify and validate the tools, methodologies, and materials developed in Phase 2.

[15] Paul Pantelis, "Sustainment Tech Area," AMRDEC briefing to ASB, 17 March 2015, AMRDEC Aviation Development Directorate – AATD.

[16] Paul Pantelis, Chief, Sustainment Tech Area, AMRDEC Aviation Development Directorate - AATD, private communication, Sept. 25, 2015.

A noteworthy example of Navy efforts to develop CBM capabilities for rotary wing aircraft is its ongoing development of an Integrated Hybrid Structures Management System (IHSMS) as an important element of its Future Naval Capabilities program.[17] Its focus is on rotor and airframe components of USMC CH-53K helicopters. Principal objectives include reducing total ownership costs, increasing operational availability, and improving flight safety. The work includes developing advanced capabilities for load/load-history tracking for dynamic components and airframe hot spots, damage detection and monitoring, damage growth and criticality prediction, and micro-climate environmental monitoring. Enabling capability metrics/goals include significant reductions in material maintenance costs, maintenance man hours per flight hour, and weighted elapsed maintenance time. Detailed design work for the system architecture and technology integration on CH-53K have been completed, and planned functional and risk reduction tests are in progress.

Air Force activities to develop advanced CBM capabilities for fixed wing aircraft include sustainment work involving diagnostics and prognostics advanced technology development, particularly for aircraft engines. Near-term goals include the development of improved non-destructive inspection (NDI) tools. Mid-term goals include development of advanced automated NDI tools, CBM plus structural integrity, and probabilistic life prediction tools. Over the longer term, prognostics capabilities are intended to be an integral part of aircraft engine development. Ongoing Air Force Sustainment Transition efforts are intended to demonstrate selected sustainment technologies for transition into AF systems to increase readiness, reduce life cycle costs, and extend service life. They include assessment activities involving NDI and structural health monitoring for state awareness and diagnostics; prevention activities involving redesign, life enhancement, repair practices, and replacement concepts; and management practices involving fleet management, decision tools, reliability improvements, and infrastructure. Active Propulsion Sustainment efforts seek to demonstrate and transition technologies that improve safety, readiness, and cost. Technologies under development include prognostic health monitoring as an integral part of aircraft engine development.[18]

Various analyses have demonstrated the potential and realizable benefits of CBM capabilities. An early Army cost/benefit analysis for HUMS reported "an advantage in flight hours completed and operation readiness rates, coupled with a marginal decline in hours of non-mission capable for maintenance reported."[19] A more recent Army analysis indicated that CBM+ efforts as of 2012 had demonstrated notable benefits with respect to combat power (mission capable rates) and aviator safety.[20] CBM-equipped aircraft demonstrated the ability to generate more flying hours

[17] NAVAIR, "Integrated Hybrid Structural Management System (IHSMS)," briefing to ASB, June 25, 2015, DISTRIBUTION D.

[18] C. Douglas Ebersole, "Next Generation Aerospace Systems," Air Force Research Laboratory briefing to ASB, Aerospace Systems Directorate, 7 July 2015, DISTRIBUTION D.

[19] MAJ Marc P. Gaguzis, op. cit.

[20] US Army Aviation and Missile Command, *Army Aviation Condition Based Maintenance Plus (CBM+) Initiative Cost Benefit Analysis (CBA)*, 23 Jan 2012, AMCOM G3 Operations, Command Analysis Directorate.

than the non-equipped fleet, lower mission-abort rates (up to 19.6% depending on platform variant), and contribute to enhanced safety through accident avoidance. The use of CBM equipment to accurately record flight hours was estimated to reduce scheduled maintenance burden by 12-22%, with corresponding savings in contractor labor and mean time between failures. Further, the Army Aviation CBM+ initiative was reported to be responsible for "hundreds of small, nearly unquantifiable gains in terms of troubleshooting time, precautionary landings that did not happen, avoided unnecessary maintenance procedures, and more." A business case analysis for the Navy IHSMS program previously described has shown a positive return on investment with respect to cost benefits and significant reductions in maintenance man hours and elapsed maintenance time.

For the Army, commitment to CBM+ has been Aviation first, and the importance of CBM practices to Army Aviation has long been recognized. In 2004, an *Army Aviation* article noted the great potential offered by CBM technology to monitor the health of aviation systems and subsystems through the use of on-board diagnostics (near-term goal) and on/off-board prognostics (long-term goal), leading to component reliability improvements, reduced maintenance manhours, and reduced aviation accidents and incidents.[21] Such capabilities were projected to lead to "a fully modernized and transformed sustainment environment for the future that supports multifunctional, expeditionary and combined-arms units on a distributed, non-linear battlefield." In a 2006 *Army* article, the Commander, US Army Aviation and Missile Life Cycle Command reiterated that potential and stated that the "Army's vision is to achieve CBM+ goals by the end of fiscal year 2015," but noted that "transition to CBM+ is contingent on incorporating enhanced technology on existing aviation systems and embedding those capabilities into future and developmental aviation systems."[22] Due to significant technical and implementation challenges, that goal has not been realized to date, even though large numbers and a variety of diagnostic sensors of various types have been incorporated into fielded aircraft. Nevertheless, continuing progress in the development of sensing and reporting technologies over many years has enabled the emergence of CBM practices as the desired standard for Army rotorcraft, and the Army remains committed to achieving the principal CBM+ goals: (1) reducing burdensome maintenance tasks currently required to assure continued airworthiness, (2) increasing aircraft availability, (3) improving flight safety, and (4) reducing sustainment costs.[23] The functional capabilities intended to be implemented on all Army aircraft onboard CBM systems include engine monitoring, dynamic system component monitoring, structural monitoring, exceedance recording, usage monitoring, electronic logbook interface, and electronics.

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[21] LTC Kimberly Emberle, "Condition Based Maintenance: What It Means to Army Aviation," *Army Aviation Magazine*, December 31, 2004, pp. 48-50.

[22] MG James H. Pillsbury, Condition Based Maintenance for Army Aviation, Army Magazine, January 2006, pp. 27-30.

[23] AMCOM and PEO Aviation, *Condition Based Maintenance System for US Army Aircraft,* ADS-79D-HDBK, 7 March 2013, http://everyspec.com/ARMY/ADS-Aero-Design-Std/download.php?spec=ADS-79-HDBK_2013.049364.pdf.

Despite considerable interest in and extensive RDT&E activity directed toward the development of advanced CBM+ capabilities for defense systems, clear commitments by DoD and the Services, considerable progress in selected areas, and noted recorded benefits, overall progress toward comprehensive implementation of CBM+ practices has been slow. CBM in many respects remains in an extended mid-state of development due to its overall complexity – reflected in part by the extensive range of relevant Army RDT&E activities summarized in Appendix E – and numerous technical and implementation challenges. An overarching problem is that the substantial infrastructure required for CBM did not exist when the Army committed to it, including diagnostic tools for data collection, established data analysis methodology, and effective "big data" management systems. Another factor contributing to the comparatively slow rate of CBM implementation is that program managers for specific systems and other interested groups, including depot maintenance personnel, logistics specialists, and financial managers, need to be made more fully aware of CBM benefits, commit to an integration plan, and then find the required resources. Differing interests and concerns of certain elements of the Army Aviation community have also had an impact.[24]

Diagnostic sensors of various types capable of providing information regarding vibration, stress and strain, cycle times, temperature, wear, and more of many system components, sometimes in combination with environmental factors (desert, arctic, high-humidity, usage, profiles, and more) have been applied to numerous Army aircraft. They reportedly are capable of generating hundreds of megabytes of data per aircraft per flight hour. But that data needs to be stored, moved, and analyzed in the context of detailed knowledge regarding degradation and failure of critical components. Obtaining such knowledge requires extensive testing under realistic operating conditions. The ability of diagnostic devices to accurately and reliably identify, classify, and quantify emerging problems under such conditions must be firmly established. Required robust data/information management systems remain under development, analyzing overwhelming amounts of flight data presents a significant challenge for engineers, too little is known regarding dominant degradation and failure mechanisms for many critical components, and the extensive testing of innumerable system components is cost prohibitive. The comprehensive component performance data and statistical confidence that lie at the heart of developing reliable prognostic algorithms is lacking. Although CBM+ can manage unscheduled maintenance needs very well by providing useful information suggesting that a particular component is exhibiting an off-nominal condition, leading to proactive maintenance action, false alarms can be problematic by requiring maintenance attention when none might be required. In that context, diagnostic and prognostic tools need to be more reliable than the components being assessed. Another limitation is that CBM processes require the ability to detect "graceful degradation" of monitored components; they cannot lessen the consequences of unanticipated catastrophic component failures. As noted in Army Regulation AR 750-1, "CBM does not lend

[24] Christopher Smith, US Army AMCOM, formerly the CBM lead for Army Aviation, private communication, 14 September 2015.

itself to all types of equipment or possible failure modes and therefore will not be the sole type of maintenance practiced."[25]

The Army's longstanding interest in CBM+ processes is driven by their proven ability to enhance weapon system and equipment performance, contribute to enhanced readiness, enable more efficient maintenance, reduce logistics footprints, and provide significant cost savings, as previously noted. Comprehensive implementation of CBM+ processes is essential to achieving a desired Army objective of "near-zero maintenance aircraft" (ZMA) for well-defined operational periods. The concept refers to the goal of establishing a Maintenance Free Operating Period (MFOP) during which an aircraft can be expected to operate effectively for a specified number of flight hours, requires no scheduled maintenance actions, and maintains a high Operational Availability (A_O) during which it is able to perform a high percentage of intended mission profiles. Army goals for MFOP are 480 flight hours (Threshold) and 720 flight hours (Objective). Stated goals for A_O are 90% (Threshold) and 95% (Objective). Additional goals associated with the ZMA concept involve Mean Down Time (MDT) and Mean Time to Repair (MTTR) (unscheduled). MDT goals are the lesser of 4.5 days or 216 maintenance man hours (Threshold) and the lesser of 3.0 days or 144 maintenance man hours (Objective). MTTR goals are 3.0 maintenance man hours (Threshold) and 1.5 maintenance man hours (Objective).[26]

Given the current state of development of CBM+ capabilities, these goals must be viewed as potentially achievable only over the long-term, principally for FVL platforms where the appropriate means for incorporating CBM+ diagnostics and data management capabilities have been made an integral part of the aircraft design process. CBM+ implementation to the extent required to achieve near-zero maintenance capabilities for legacy aircraft presents near-insurmountable challenges because aircraft design, maintenance management procedures, and Army maintenance policy were not developed to be consistent with actual CBM+ practices. It may also be cost-prohibitive, where, as noted in Army Regulation AR 750-1, "CBM is best implemented as early as possible in the systems life cycle to minimize costs." While continuing to incorporate additional emerging CBM+ capabilities into legacy aircraft can be expected to enhance operational availability and provide maintenance cost and logistics benefits, it is not likely to achieve the stated goals of the ZMA concept for these aircraft.

3.3 Manned-Unmanned Teaming

Current Army Aviation UAS assets consist of the Raven, Puma, Shadow and Gray Eagle systems. These systems are all fixed wing, have limited autonomy, limited Manned-Unmanned Teaming (MUM-T) capability, and are essentially dedicated to a single mission (ISR, although Gray Eagle can carry Hellfire missiles in addition to ISR payloads). Currently AH-64E Apaches have capability for LOI 4 control (see Figure 3-3) of Shadow and Gray Eagle. Collaboration by means of MUM-T is constrained by lack of autonomy and by the UAS communications architecture; the UAS communicate primarily with ground control systems rather than directly with each other or with

[25] Department of the Army, *Army Regulation AR 750-1, Army Materiel Maintenance Policy*, 12 September 2013, http://www.apd.army.mil/pdffiles/r750_1.pdf.

[26] Paul Pantelis, private communication, op.cit.

other aviation assts. The lack of autonomy also adversely impacts the cost to operate UAS, because one or more operators are required for each UAS.

Level 1 – Indirect receipt/transmission of UAS related payload data
Level 2 – Direct receipt of UAS video and other sensor information
Level 3 – Control of the camera and sensors on the UAS
Level 4 – Control of the flight path and payloads
Level 5 – Full control of the UAS, including takeoff and landings

Figure 3-3. MUM-T Levels of Interoperability

Army Aviation recognizes the limitations associated with current UAS operability and has plans to improve autonomy and MUM-T capabilities. A key effort is the Synergistic Unmanned Manned Intelligent Teaming (SUMIT) program, described in Figure 3-4. This multi-year project is intended to demonstrate an integrated suite of aiding and autonomy technologies that will enable aviators to exploit UAS as an integral part of collaborative manned-unmanned teams. While these goals are noteworthy, the funding currently being provided to accomplish them is only about $5M/year.

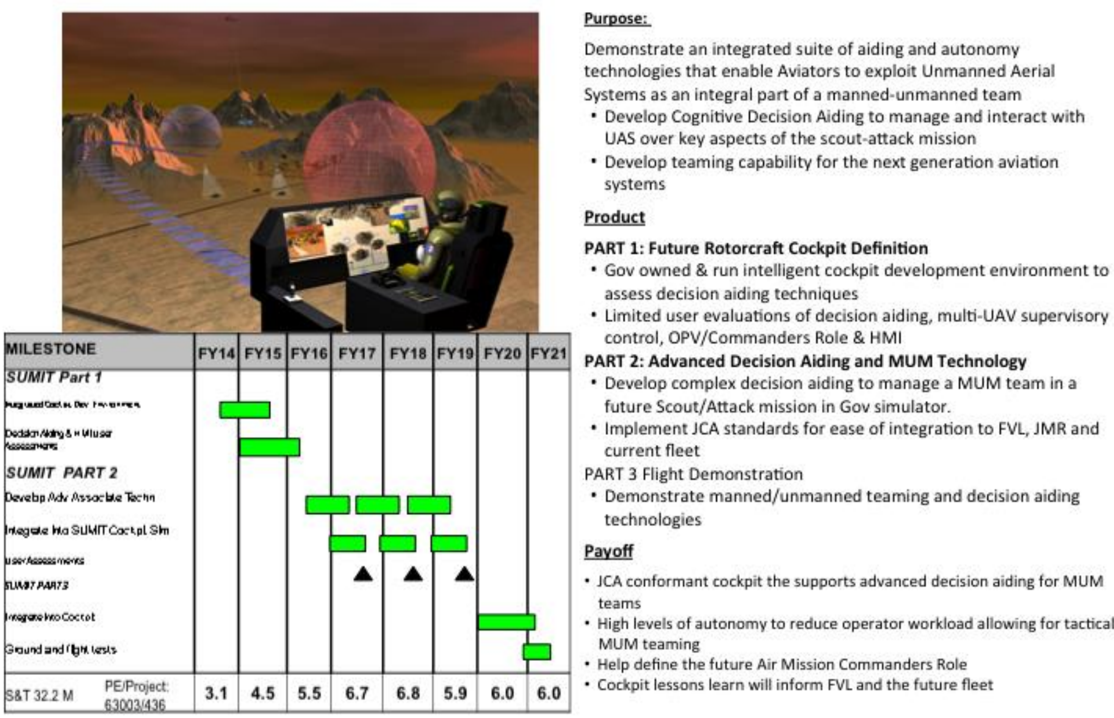
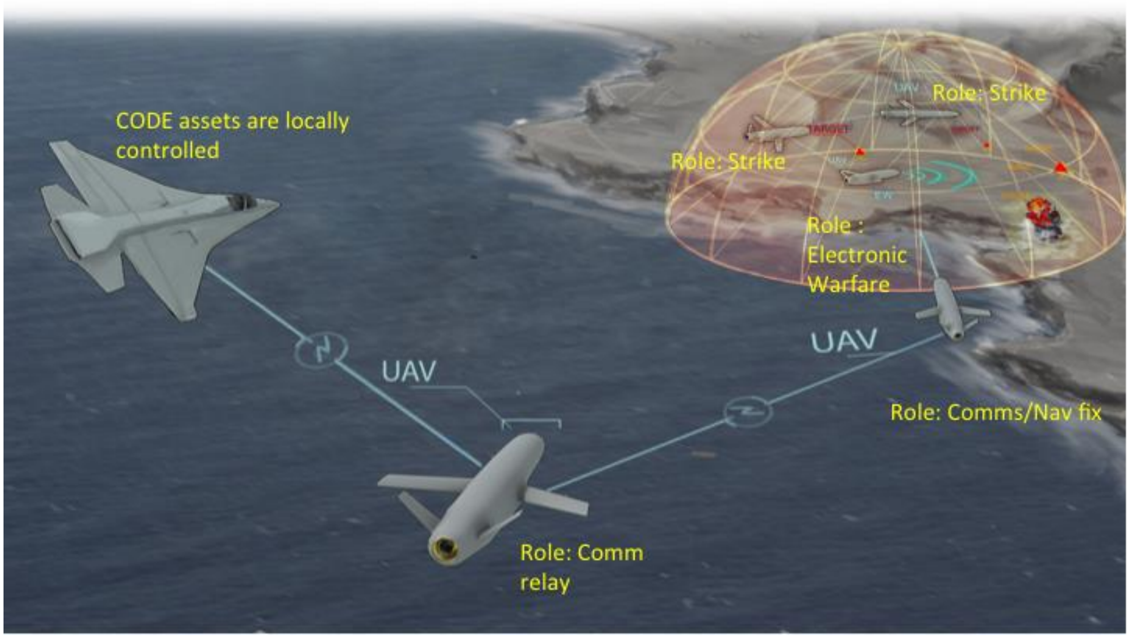


Figure 3-4. The Synergistic Unmanned Manned Intelligent Teaming (SUMIT) Effort

AMRDEC is also working with DARPA on the Collaborative Operations in Denied Environment (CODE) program, which is investigating collaboration not just of a UAS with a manned system but also among a number of UAS with distributed functionality, as illustrated in Figure 3-5. The program is specifically looking at expanding the mission capabilities of UAS through increased autonomy and inter-platform collaboration. In this concept, the manned aircraft serves as the mission supervisor, but much of the functionality to prosecute the mission is distributed onto low-cost UAS systems, which operate autonomously unless directed by the mission supervisor. Distributing the functionality improves mission effectiveness and survivability in two ways. First, it greatly complicates threat response and adds another survivability layer around the high-value manned asset that the threat must defeat. Secondly, it allows much of the functionality that would normally be required to be carried on one high-value manned asset off-loaded to relatively inexpensive modular UAS that can be tailored to carry payloads required for a particular mission. This reduces the ratio of cost of potential blue force asset loss to threat cost. At some acceptable low-cost level, the UAS platforms might be considered as "attritable."



Source PM UAS briefing

Figure 3-5. DARPA/AMRDEC Collaborative Operations in Denied Environment (CODE)

The SUMIT and CODE projects are noteworthy and can provide a good basis for the *eventual* development and deployment of semi-autonomous (i.e., supervised autonomy) UAS and collaborative MUM-T. However, greater emphasis and funding will likely be necessary to ensure that "eventual" falls within the 2025-2040 timeframe.

3.4 Survivability/Lethality

Army Aviation rotorcraft are an indispensable component of Army forces and play a critical role in the successful conduct of Army ground combat operations. The survivability, lethality, and overall operational effectiveness of these assets is of paramount importance as they provide attack/reconnaissance capability in support of ground operations, assault capability in moving troops and equipment around the battlefield, logistics support, and medical evacuations. Significant threats to aircraft survivability include enemy man-portable air defense systems (MANPADS), surface-to-air and air-to-air missiles, enemy UAS, electronic warfare and DE threats, and small- and medium-caliber projectiles from ground fire in pickup and landing zones. Aircraft survivability against such a broad spectrum of current, emerging, and projected future threats requires the development of synergistic survivability capabilities that include integrated planning, teaming, and both active and passive technologies.

Considerable discussion of rotorcraft survivability against such threats was provided in Section 2.1.1, which particularly emphasized the layered approach to survivability represented by the survivability "onion" depicted in Figure 2-9. Outer layers of the overall approach require capabilities to avoid detection and engagement, which can be achieved through EO/IR and acoustic signature reduction, other advanced technologies, and new CONOPS and TTPs. Improved situational awareness, more effective active countermeasures, and greater aircraft agility/maneuverability can enhance Army Aviation survivability by inhibiting detection and engagement by adversaries. Inner layers of the multi-layered approach are concentrated on avoiding or absorbing damage and avoiding catastrophic destruction, enabling the aircraft to complete its mission and remain available for future service. Armoring selected areas (providing passive protection systems for pilots and critical aircraft components against conventional small- and medium-caliber ballistic threats), incorporating redundancy into the most mission-critical systems, exploiting high-durability and damage-tolerant design features and materials, and various other factors, including advanced TTPs and training, are all important to enhancing survivability. The ability of rotorcraft to operate in degraded visual environments (DVE), discussed in Section 3.1.1 above, can also be expected to contribute to aircraft survivability by reducing aircraft visibility in the visual and IR spectral regions, thereby helping to avoid damage. Coordinated MUM-T operations, discussed in Section 3.3, represent another important potential contributor to future aircraft survivability.

A comprehensive range of integrated survivability capabilities is being actively investigated in Army research and development efforts by AMRDEC's Advanced Development Directorate. The work includes technologies important to all of the survivability layers depicted in Figure 2-9. Detailed discussion of those efforts is beyond the scope of this ASB study, but it may represent an opportunity for a future study focused principally on Army Rotorcraft Survivability and Lethality. Two specific AMRDEC/ADD aircraft survivability programs of note, however, are the Route Optimization for Survivability Against Sensors (ROSAS) program and the Close Combat Survivability (CCS) program.[27] A stated goal of the ROSAS program is to "demonstrate a real-time route planner function to provide rapid and survivable routes to safely evade the full spectrum of dynamic pop-up threats in complex terrain" and enable the aircraft to complete its mission objective. Payoffs include improved situational awareness and increased survivability of warfighters and aircraft against a robust spectrum of threats. Flight demonstrations on a test range of Modular Integrated Survivability (MIS) hardware and software are scheduled for FY2017. The CCS program seeks to develop and demonstrate "next-generation signature-reduction capabilities to delay/deny aircraft acquisition and engagement by the full spectrum of portable threat weapons." The program includes a focus on technologies that provide low rotorcraft

[27] Torrey Deas, "Mission System Survivability Technical Area Program Overview," AMRDEC/ADD briefing to ASB, March 2015.

contrast against sky and terrain backgrounds under diurnal conditions. It also includes work to design an adaptive IR engine suppressor capability to optimize IR signature reduction and aircraft lift and range performance, as well as to develop real-time aural detection algorithms that include aircraft maneuver data. CSS program advances, which are transitioning into the Signature Reduction for Advanced Threats (SRAT) effort in FY2016, are intended for eventual transition to both the current and future fleet.

Army Aviation lethality principally derives from weapons deployed on Apache AH-64 platforms. The Apache is the Army's primary attack helicopter, described as "a quick reacting, airborne weapon system that can fight close and deep to destroy, disrupt, or delay enemy forces."[28] It was designed to fight and survive both during the day and at night, as well as in adverse weather conditions. Apache armament provides lethal capabilities against a wide range of targets. The most lethal weapon system deployed on the Apache is the 16 AGM -114 Hellfire missiles; up to 16 missiles can be carried in pods mounted on the stub wings. Hellfire variants featuring either tandem shaped charge, blast/frag, or thermobaric warheads are highly lethal/effective against medium- and heavy-armored combat vehicles, buildings, bunkers, and selected other high-value targets. Precision guidance over an effective range that extends out to about 8 km is provided by semi-active laser or mm-wave radar seekers. The lethality of Hellfire missiles has been demonstrated in recent combat operations in the Persian Gulf, Afghanistan, and Iraq.

Other highly lethal armament deployed on AH-64 Apaches include 70mm (2.75-inch) Hydra rockets, a 30mm M230 chain gun, and AIM-92 Air-to-Air Stingers (ATAS). The Hydra rockets provide lethal effects against enemy personnel, light armored vehicles, and other soft materiel targets; up to 76 rockets can be carried in pods mounted on the Apache stub wings. The M230 chain gun is an area weapon system providing accurate air support with minimal collateral damage. It produces lethal effects on various light- and medium-armored vehicles, enemy personnel, and other ground targets. The gun fires 30mm High Explosive Dual Purpose (HEDP) M789 ammunition to ranges of about 3 km with both significant penetration and fragmentation effects; lethal radius against unprotected, standing enemy combatants is about 3 m. Ongoing work at ARDEC is developing an M789 upgrade that will enhance M230 chain gun lethality by incorporating proximity fuzing and controllable air burst capabilities. The AIM-92 Stingers, which were developed from the shoulder-launched ground-to-air FIM-92 Stinger system, contain a blast/frag warhead with lethal capability against enemy fixed-wing and rotary-wing aircraft. Figure 3-6 shows the weapons loadout for an Apache AH-64. All of these systems are carried externally. As the Army transitions to higher speed rotorcraft, more aerodynamic designs will be required; effective means of internal carry must be incorporated into new platform designs.

[28] Global Security, "AH-64 Apache," downloaded February 2016 from http://globalsecurity.org/military/systems/aircraft/ah-64.htm


Figure 3-6. Weapons Loadout for AH-64 Apache

The Black Hawk UH-60 is the Army's front line utility helicopter used for troop transport, air cavalry, aeromedical evacuations, and selected other missions. Lethal capabilities for most Black Hawks are provided by two pintle-mounted M60D or M240H 7.62mm machineguns located at the crew chief and gunner stations. The rate of fire for these weapons, which provide self-defense and fire-suppression capabilities, is about 600 rounds/min for the M60D and 750 rounds/min for the M240H. Their effective range is about 1100 meters.[29] Black Hawks fitted with the External Stores Support System (ESSS), which incorporates two stub wings each containing two hard points, provide significant potential for enhancing platform lethality by enabling deployment of an impressive array of additional armament. The enhanced lethal capabilities of such Black Hawks is reflected in the MH-60M Blackhawk, a highly specialized UH-60 variant developed for both assault and attack missions by Special Operations forces. The MH-60M is capable of carrying Hellfire missiles, air-to-air Stinger missiles, 70mm (2.75-inch) Hydra rockets, medium-caliber gun pods, or the Volcano minefield dispersal system. Additional armament can include two 7.62mm M134 Miniguns, forward facing, used for self-defense and landing zone fire suppression; the M134 is capable of firing up to 6000 rounds/minute and has an effective range of about 1000 meters.[30] Figure 3-7 shows an MH-60M Black Hawk firing a salvo of 2.75-inch rockets.

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[29] Operator's Manual for Helicopters, Utility Transport, TM 1-1520-280-10, HQDA, 14 August 2009, Distribution D.

[30] American Special Ops, "MH-60M Black Hawk Helicopter," downloaded February 22016 from http://www.americanspecialops.com/night-stalkers/helicopters/mh-60.php

Figure 3-7. MH-60M Black Hawk Firing a Salvo of 2.75-inch Rockets

The primary mission of Chinook CH-47 aircraft is to provide transport of troops, artillery placement, and battlefield resupply of ammunition, fuel, water, barrier materials, and other supplies and equipment. Other missions may include medical evacuation, aircraft recovery, firefighting, parachute drops, heavy construction, disaster relief, and search and rescue operations. CH-47 lethality is provided by pintle-mounted M60D or M240 7.62mm machineguns mounted in the forward right cabin door, left cabin escape hatch, and at the rear loading ramp to provide self-defense and fire-suppression capabilities similar to the Black Hawk UH-60. As noted for the Black Hawk, the rate of fire for these weapons is about 600 rounds/min for the M60D and 750 rounds/min for the M240H, with an effective range of about 1100 meters for both weapons.[31] The accuracy of some of these guns may be enhanced by co-aligned IR and visible lasers. The IR laser is intended to be used with night vision devices.

Additional lethal capabilities provided by Army Aviation are associated with the current and potential future use of UAS, MUM-T, and DVE. Gray Eagle is currently the only unmanned aircraft system deployed by the Army that carries armament. The aircraft has four hard points that can carry Hellfire AGM-114 missiles that are particularly effective against enemy main battle tanks and other hard, high-value targets. They provide a lethality complement to Apaches while eliminating the risk to Apache aircraft and crew. Small UAS swarms, under consideration for future development, can add an exciting advanced capability to air/land combat operations when

[31] Technical Manual, Operator's Manual for Army CH-47F Helicopter, TM 1-1520-271-10, HQDA, 18 December 2013

new CONOPS and TTPs are developed to exploit their potential. UAS and coordinated MUM-T operations, discussed in Section 3.3 and including the SUMIT and CODE efforts, will also add a new facet to Army Aviation lethality. As previously noted, the AH-64E currently has the capability to control the Shadow and Gray Eagle flight path and payload. In addition to enhancing Army Aviation survivability, emerging DVE capabilities, discussed in Section 3.1.1, also offer important potential lethality benefits. The stated goal of the RDECOM/AMRDEC DVE-Mitigation (DVE-M) program is “to convert DVE into a combat multiplier,” to create an advanced capability that enables commanders “to conduct operations deliberately in DVE with confidence” and ensure that their mission will be successful. DVE can provide a disruptive capability advance help “to maintain an asymmetric advantage on the battlefield, much like night vision technology.”[32] Such an advantage will clearly enhance overall Army Aviation lethality.

Over the past decade, directed energy weapons have made significant technological advances in terms of power and effectiveness. One specific DE technology showing particular promise is optical fiber lasers, which are energy efficient, compact, and experiencing significant continuing technical advances. Such directed energy weapons have an “infinite" magazine and reach targets at the speed of light. It is important to note that both allies and potential adversaries have the technological capability to develop and field capable directed energy weapons, with both offensive and defensive applications. The Army should strategically plan for and embrace the future deployment of directed energy weapons on different types of Army Aviation platforms for both survivability and lethality purposes.

3.5 Platform Technology

3.5.1 Overview

The platform technologies S&T portfolio is designed to explore, develop, and transition critical technologies that enhance the performance, effectiveness, affordability, and survivability of Army Aviation. The ASB considers the portfolio to be generally well-balanced for manned systems; ongoing engine programs are especially well structured. There are two big-picture recommendations that clearly need to be implemented moving forward:

1. For manned systems, Army Aviation platform technologies must continue to be developed to support not only the modernization of the legacy fleet but also future vertical lift, especially in light of the ASB Recommendation Set #5, FVL with Speed and Simplicity. (See Section 4.5)
2. In light of the ASB Recommendation Set #3, UAS Vehicles, the platform technologies portfolio must be expanded and/or redirected to provide more focus on unmanned systems (see Section 4.3).

Five objectives have been laid out by AMRDEC for platform technologies that are designed to provide significant payoffs, including increased mission radius, increased payload capability, reduced O&S costs, decreased maintenance downtime, increased mission availability, and

[32] Kristofer Kuck, “RDECOM Rotorcraft DVE-Mitigation (DVE-M) Program,” AMRDEC/ADD briefing to ASB, 17 March 2015.

improved crew protection/survivability. As mentioned earlier, the ASB considers this portfolio to be reasonably balanced for manned systems and, with proper focus, many of the efforts can support unmanned platforms as well. These five objectives are:

1. Improve the weight, noise, and durability and cost of rotorcraft drive systems;
2. Improve the power-to-weight ratio, specific fuel consumption, durability and cost of turboshaft engines;
3. Provide lightweight, durable, and reliable structures for extreme environments and high op-tempo scenarios;
4. Improve crashworthiness and aircrew protection from conventional threats and directed energy weapons;
5. Reduce sustainment costs by providing usage-based designs, health-based adaptive controls, prognosis-based inspections/maintenance scheduling, and reliable designs.

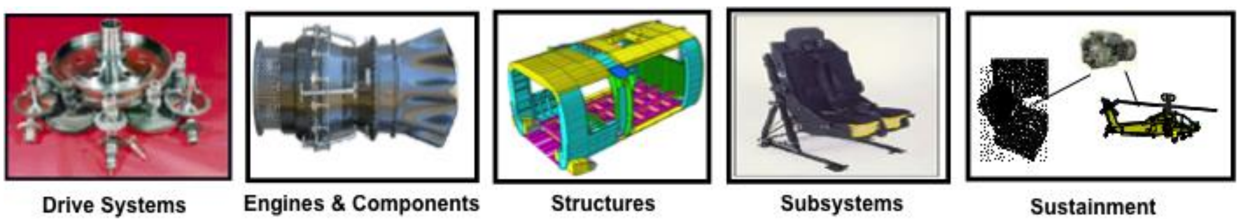

Figure 3-8. The Five Focus Areas for Army Aviation Platform Technologies

3.5.2 Drive Systems

Army Aviation's drive system S&T portfolio, described in Figure 3-9, consists of the Future Advanced Rotorcraft Drive System (FARDS) and the Next Gen Rotorcraft Transmission. As summarized in the figure, FARDS provides the aircraft drive train designers with a wide variety of validated approaches for significantly improving hp/wt ratio and reducing noise and cost compared to the existing fleet. These approaches are being achieved through advances in gearing, lubrication, housings, bearings and shafting, and materials. As the technologies mature, they are expected to transition to UH-60 and OH-58 upgrade programs.

The Next Gen Rotorcraft Transmission program is consistent with the Joint OSD Advanced Variable Speed Aircraft Transmission (AVSAT) program. Key program objectives are to demonstrate speed changing concepts (100-50% range), increase Oil Out Time by 50%, reduce O&S costs by 40%, and increase component life by 2000 hours. Transition targets are the current fleet as well as FVL. Figure 3-10 shows the Rotorcraft Drives Technical Area Roadmap.

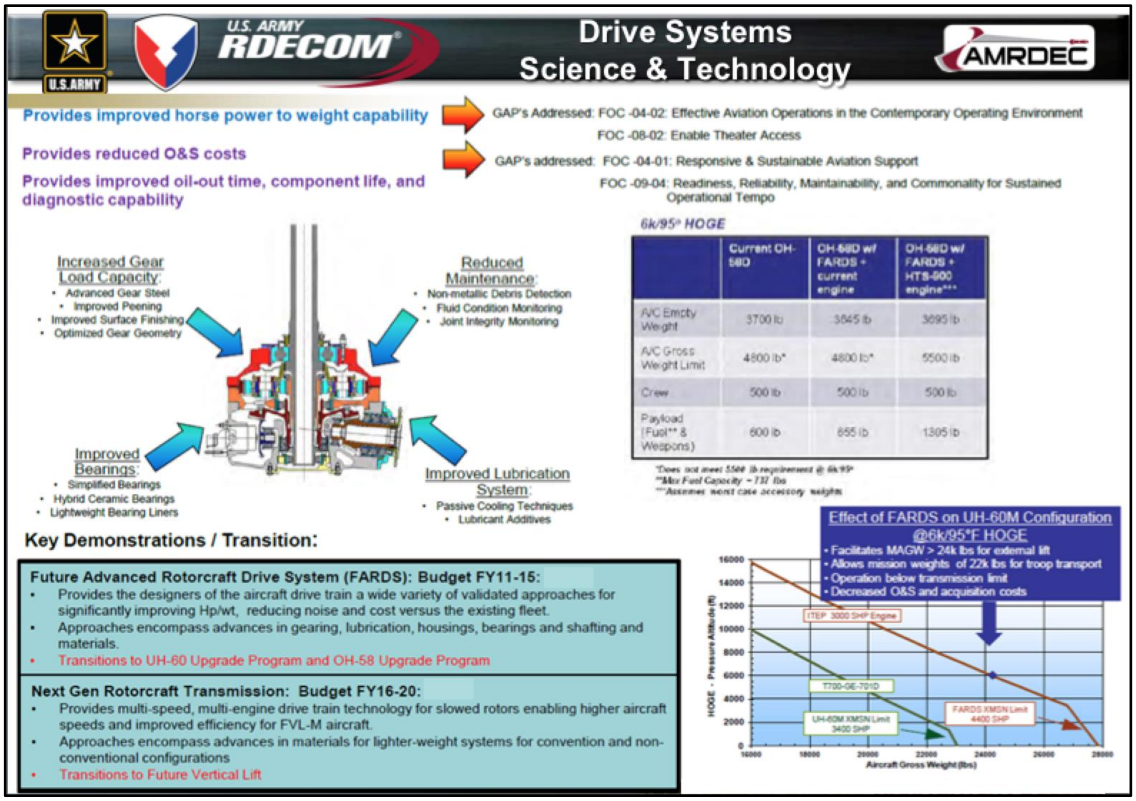

Figure 3-9. Army Drive Systems Science & Technology

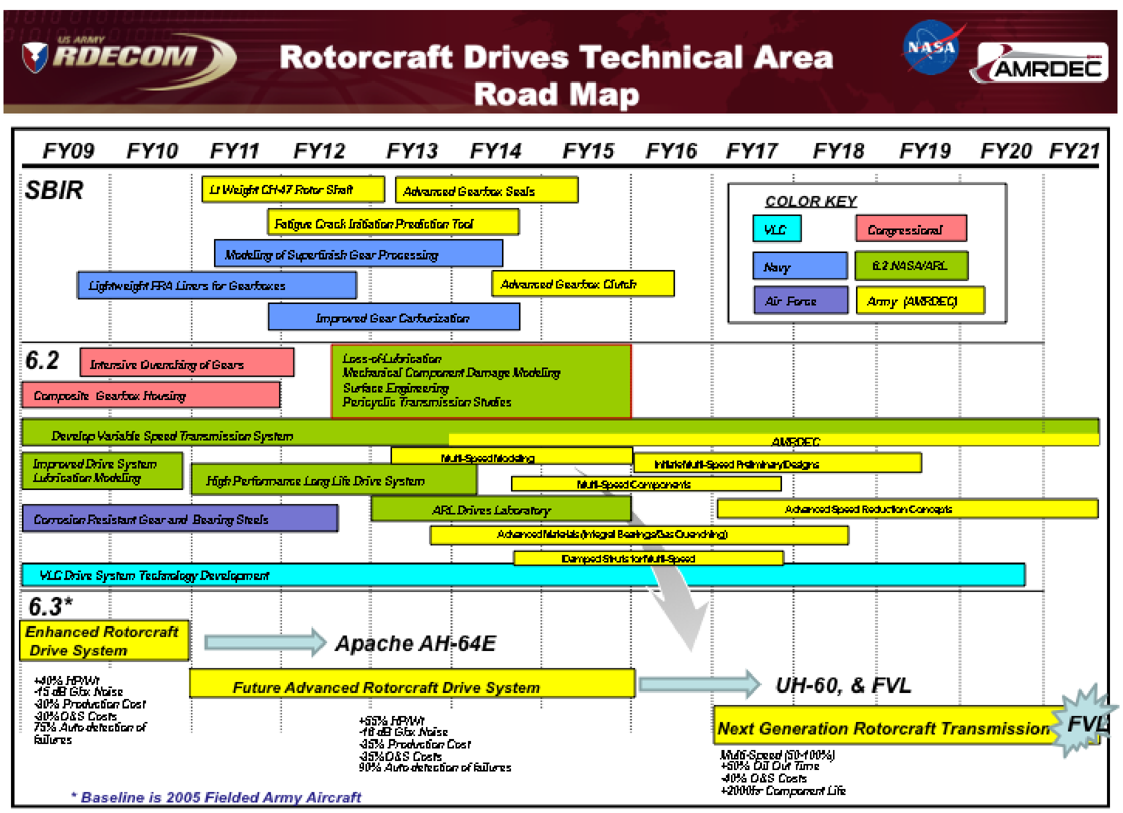

Figure 3-10. Rotorcraft Drives Technical Area Road Map

3.5.3 Engines and Components

The ASB is very supportive of the Army engine programs and believes that continuing participation in the ITEP/AATE/FATE/Alternative Concept Engine initiatives should remain a high priority. These programs are leading to superior mission capability for current and future rotorcraft, as well as for increased energy efficiency and significant O&S cost reduction, which is important since engines are the top rotorcraft O&S driver. Figure 3-11 provides an overview of the Army Engine Science and Technology initiative showing gaps being addressed and future engine attributes. Figure 3-12 provides an overview of engine technology development from component development at the 6.2 Applied Research level to engine/component qualification programs at the 6.4 Advanced Component Development and Prototypes level and on to transition to legacy aircraft and FVL. Figure 3-13 provides details on the AATE program from its purpose to develop advanced affordable 3000-hp class turboshaft engine technology for Black Hawk, Apache, and FVL aircraft to the payoffs of improved payload and hot/high engine capability, as well as reduction in production and maintenance cost and logistics footprint. An example of the superior mission capability that will be achieved for current rotorcraft is discussed in Section 4.4 Modernization of Legacy Rotorcraft Systems, where insertion of ITEP/FATE engine technology into a Black Hawk platform provides a dramatic increase in range/payload. The Army Engine S&T roadmap is also presented in Section 4.4.

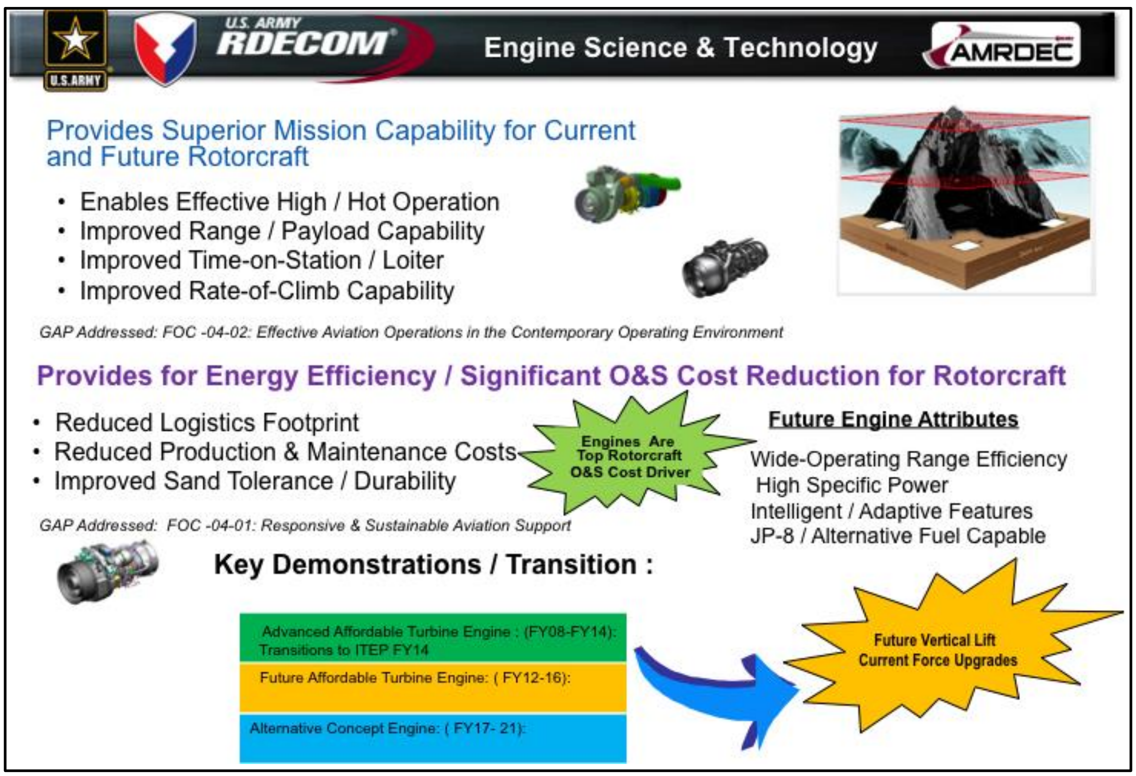

Figure 3-11. Army Engine S&T Showing Gaps Addressed and Future Engine Attributes

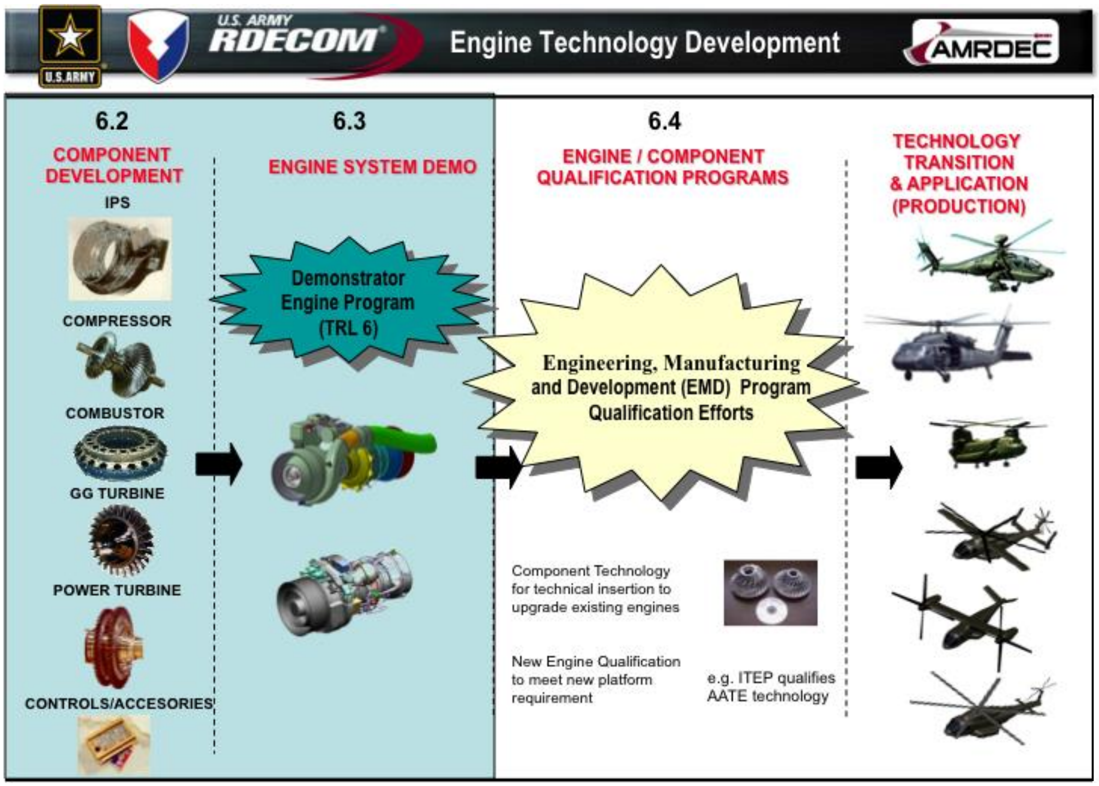

Figure 3-12. Engine Technology Development

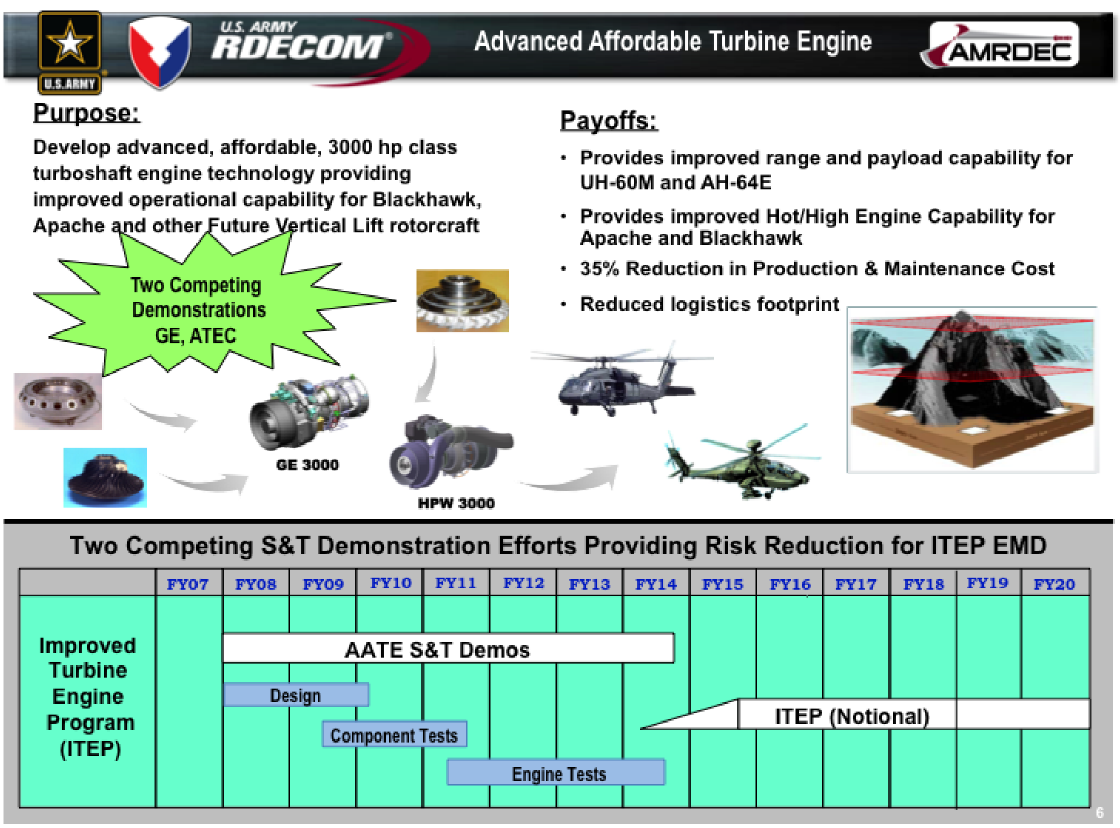

Figure 3-13. Advanced Affordable Turbine Engine (AATE), Purpose and Payoffs

3.5.4 Structures, Subsystems, and Sustainment

AMRDEC has extensive platform programs focused on structures, subsystems, and sustainment that the ASB considers to be well-balanced for manned systems. Figure 3-14 presents the Structures S&T Roadmap out to FY2020, which shows how the structures S&T portfolio supports the JMR demonstrator. Figure 3-15 provides the Subsystems Roadmap with an overview of the subsystems portfolio, which has a strong focus on aircrew survivability technologies. Figure 3-16 provides the Operations and Sustainment S&T Roadmap extending from capability-based operations and sustainment to autonomous sustainment for rotorcraft operations, and finally moving toward embedded rotorcraft sustainment technologies. Information regarding the Army sustainment efforts in the context of condition-based maintenance and near-zero maintenance aircraft are provided in Section 3.2. Ongoing RDT&E activities pertinent to the development of CBM capabilities are summarized in Appendix E.

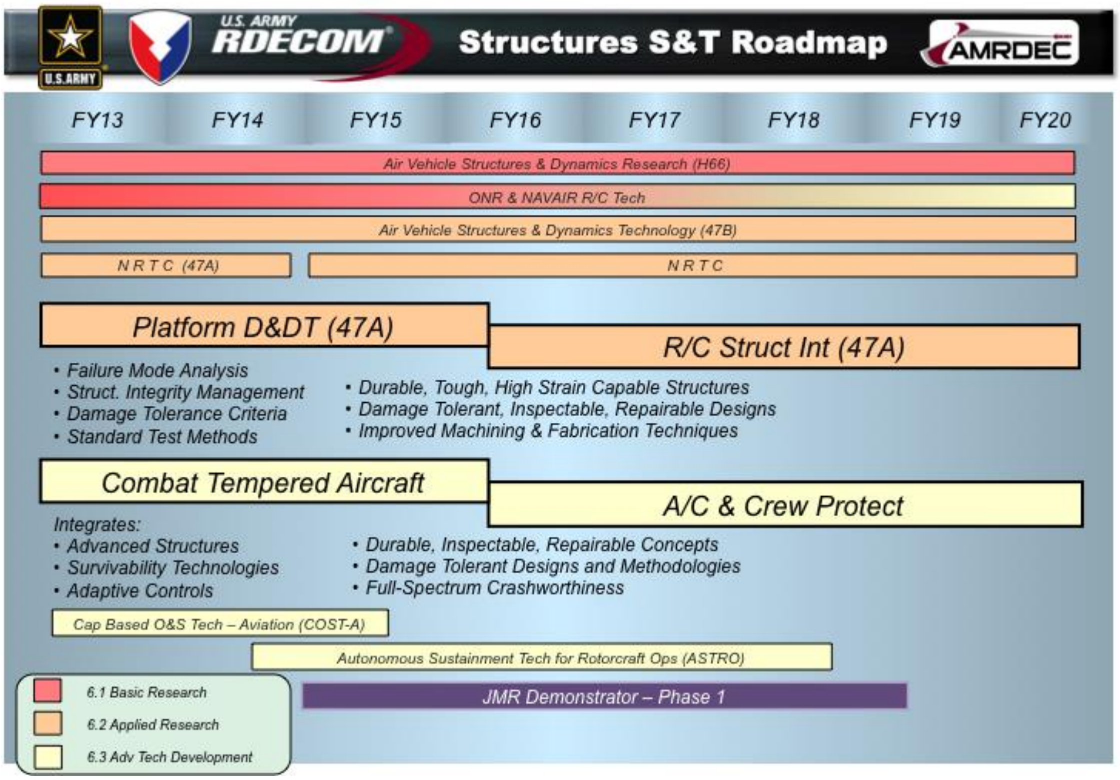

Figure 3-14. Structures S&T Roadmap

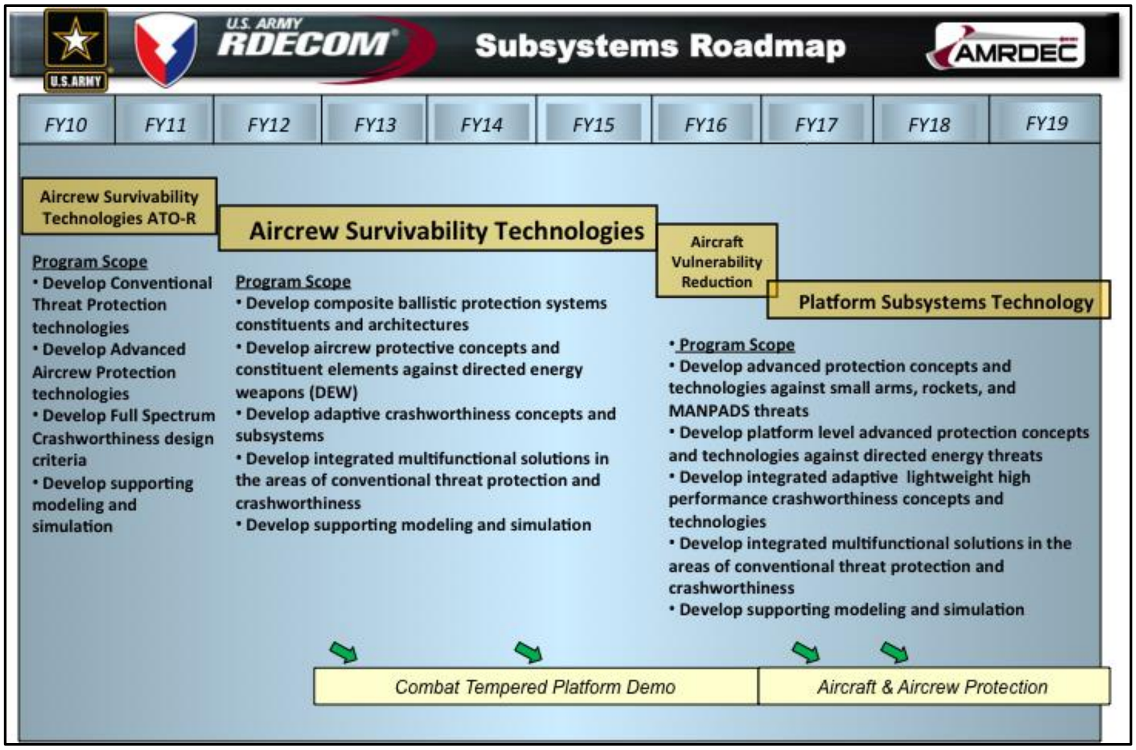

Figure 3-15. Subsystems Roadmap

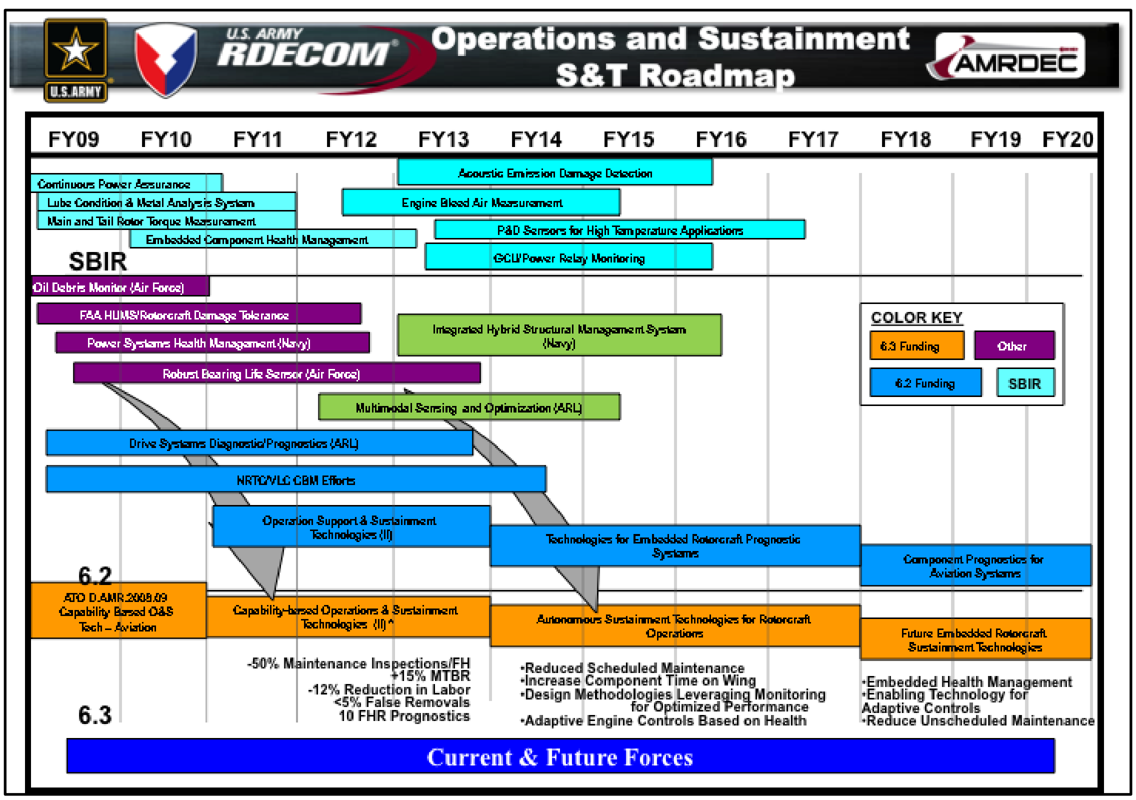

Figure 3-16. Operations and Sustainment Roadmap

4 FINDINGS & RECOMMENDATIONS

Based on the information collected, the study team developed findings and recommendations on nine topics, as summarized in Figure 4-1.

Context: Character of Warfare in 2025 and Role of Army Aviation
1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift
Addressing Capability Gaps: Development and Acquisition
8. UAS Vehicles
9. Modernization of Legacy Rotorcraft Systems
10. FVL Acquisition with Speed and Simplicity
11. Aviation Mission Systems
12. Aviation Systems Integration and Testbed
S&T Portfolio: Innovation and Game Changers
10. Advanced and Disruptive Systems S&T
11. S&T Investment Strategy

Figure 4-1. Findings and Recommendations Overview

4.1 System of Systems Operational Effectiveness Analyses

The critical challenge to Army Aviation posed by the proliferation of threats was discussed in Section 2. These threats span the spectrum from sophisticated next-generation air defenses to capabilities that utilize widely available inexpensive assets, such as swarms of small Unmanned Aircraft Systems (UAS). The continued advancement and proliferation of MANPADS and SAM systems is of particular concern. The current approach to survivability of Army Aviation systems is based on a multi-layered approach centered on the platform. The outer layer involves systems and techniques to avoid detection by a threat system, the next layer to avoid engagement by the threat, and so on. This “onion” approach has served well in the past. However, next-generation threats, and the proliferation of these advanced threats, calls into question how much longer this platform-centric approach can remain effective.

One approach to solving this platform-centric dilemma is a system-of-systems (SoS) concept, which effectively adds another layer to the “onion” outside of the platform itself. A limited number of elements of the SoS concept are already being implemented by means of the fusion of off-board information with on-board data and the recent upgrade of AH-64 to include Level 4 MUM-T capability with Shadow. However, a more robust vision for the future that takes fuller advantage of collaboration between manned and unmanned systems is required to drive SoS solutions that fully exploit the synergy of unmanned systems operating in collaboration with the manned platform at the center of the “onion.” Supervised semi-autonomous UAS can provide another layer to the onion.

Based on these findings, the first study recommendation is to conduct an SoS operational effectiveness analysis, as detailed in Figure 4-2. This analysis will result in a definition of the future

Army Aviation architecture and CONOPS for effective operations against the intense threat environment that exists now and that will only become more challenging in the 2025-2040 timeframe. This analysis must consider and fuse all elements of the Joint integrated battlespace illustrated in Figure 4-3. All other recommendations of this study are dependent upon a firm foundational knowledge of the architecture and CONOPS resulting from this analysis.

<u>Findings</u>

- Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details)
- Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs.
- A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.

<u>Recommendation</u>

- TRADOC: <u>Conduct operational effectiveness analyses</u> of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army Aviation in 2025 and beyond in complex threat environments. <u>Concepts</u> should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in GPS-denied environments, attritable UAS assets and enhanced lethality of DE. <u>Develop CONOPS and architectures</u> for the most cost-effective concepts.

Figure 4-2. Findings and Recommendation Set #1

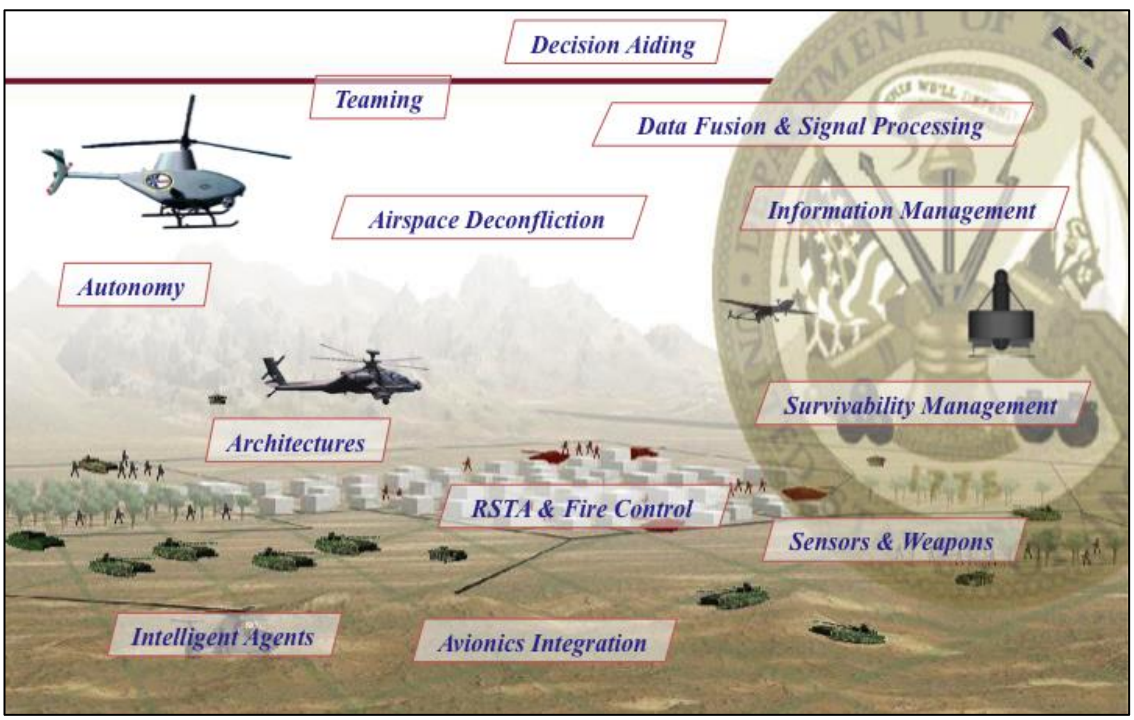

Figure 4-3. Notional Integrated Battlespace

4.2 Affordability of Heavy Vertical Lift

The pressing challenge for Army Aviation systems to satisfy the need for strategic, expeditionary, and operational maneuver of dispersed mechanized forces in austere areas of operation in the face of capable anti-access and area denial (A2/AD) threats in future conflicts was discussed in Section 2. Current Army Aviation assets cannot provide the heavy vertical lift (20-30 stons) needed for expeditionary and operational maneuver of *mechanized* dispersed forces. This need has been detailed in numerous studies, exercises, and wargames, including the 2014 Army Unified Quest exercises,[33] the 2014 ASB study on Strategic and Expeditionary Maneuver,[34] and the 2012 Army-Marine Corp Concept.[35] The capability needs for this class are documented in the Joint Future Vertical Lift (JFVL) ICD as well as the Joint Heavy Lift (JHL) ICD.

Figure 4-4. Historical Heavy Vertical Lift Options

While the capability need for a vertical heavy lift system is well documented, it is clear that the Army cannot afford to develop such a capability within current or anticipated Army TOA for the foreseeable future. Therefore, the Army may have to rely on interim solutions to providing a partial capability (see Figure 4-4). The recommendation resulting from these findings, detailed in

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33 Army Capabilities Integration Center, *Unified Quest 2014 Executive Report,* 12 Mar 2015, http://www.arcic.army.mil/Library/documents.aspx.

34 Army Science Board, *ASB FY2014 Summer Study - Decisive Army Strategic and Expeditionary Maneuver,* July 2014.

35 Army Capabilities Integration Center and Marine Corps Combat Development Command, *Gaining and Maintaining Access: An Army-Marine Corps Concept*, Mar 2012.

Figure 4-5, calls for TRADOC to reassess interim and future Joint heavy vertical lift options to determine a viable road ahead.

Findings

- Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept."
- However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040.
- Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.

Recommendation

- TRADOC: Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead
  - If development of HVL is cost prohibitive, consider alternatives.
  - If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

Figure 4-5. Findings and Recommendation Set #2

4.3 UAS Vehicles

As discussed previously in Section 2, UAS can and should play a significant and expanded role in future Army Aviation CONOPS. Although the Army UAS Roadmap[36] cites plans to upgrade current platforms and eventually to develop replacements for some, it lacks a clear vision for expanding the use of UAS as complements and extensions to manned aviation, rather than simply as stand-alone single mission (ISR) systems. Expanding the mission set and increasing autonomy for UAS are identified as far-term objectives in the roadmap, but very limited funding is currently allocated to achieving these objectives. In contrast to the Army Aviation UAS roadmap, the USAF and USN/USMC have bold visions for expanded roles/missions for UAS and greater use of collaborative MUM-T.

The rapidly advancing technologies associated with UAS, autonomous systems and MUM-T should be viewed as a significant opportunity for Army Aviation to better integrate collaborative manned-unmanned capabilities into its future force. Concepts similar to the distributed functionality SoS concept in Figure 4-6 are critically important to the survivability and lethality of Army Aviation and require a focus on introducing new UAS designs into the Army Aviation inventory and effectively integrating these new assets into a collaborative manned-unmanned environment. A major challenge in expanding the Army Aviation UAS portfolio, increasing MUM-

[36] US Army UAS Center of Excellence, "*Eyes of the Army,*" *U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .

T capabilities, and meeting a bold vision, however, is the small percentage of Army S&T funding allocated to UAS developments.

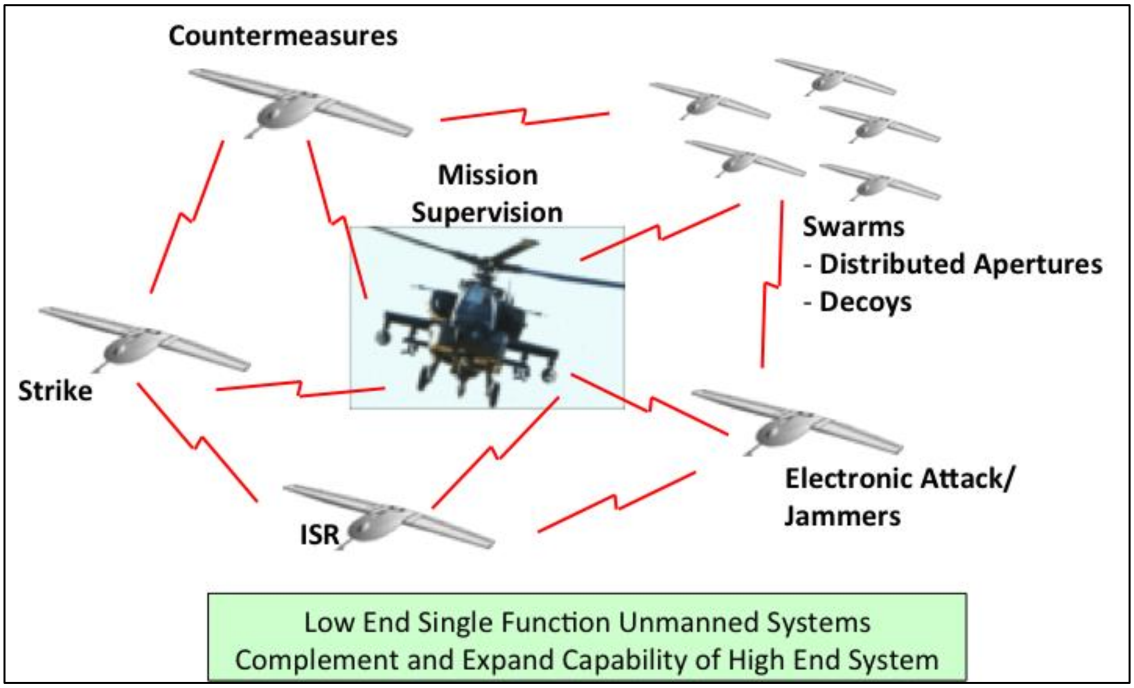


Figure 4-6. Distributed Functionality Collaborative System of Systems Concept

The ASB recommendation in this area, detailed in Figure 4-7, is for ASA(ALT) to review and revise the UAS roadmap as necessary to identify and embed near-term and future UAS that are capable of satisfying the Army Aviation SoS architecture and CONOPS that will emanate from the SoS operational effectiveness analysis (Recommendation Set #1).

Findings

- The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions.
- DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army Aviation.
- New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.

Recommendation

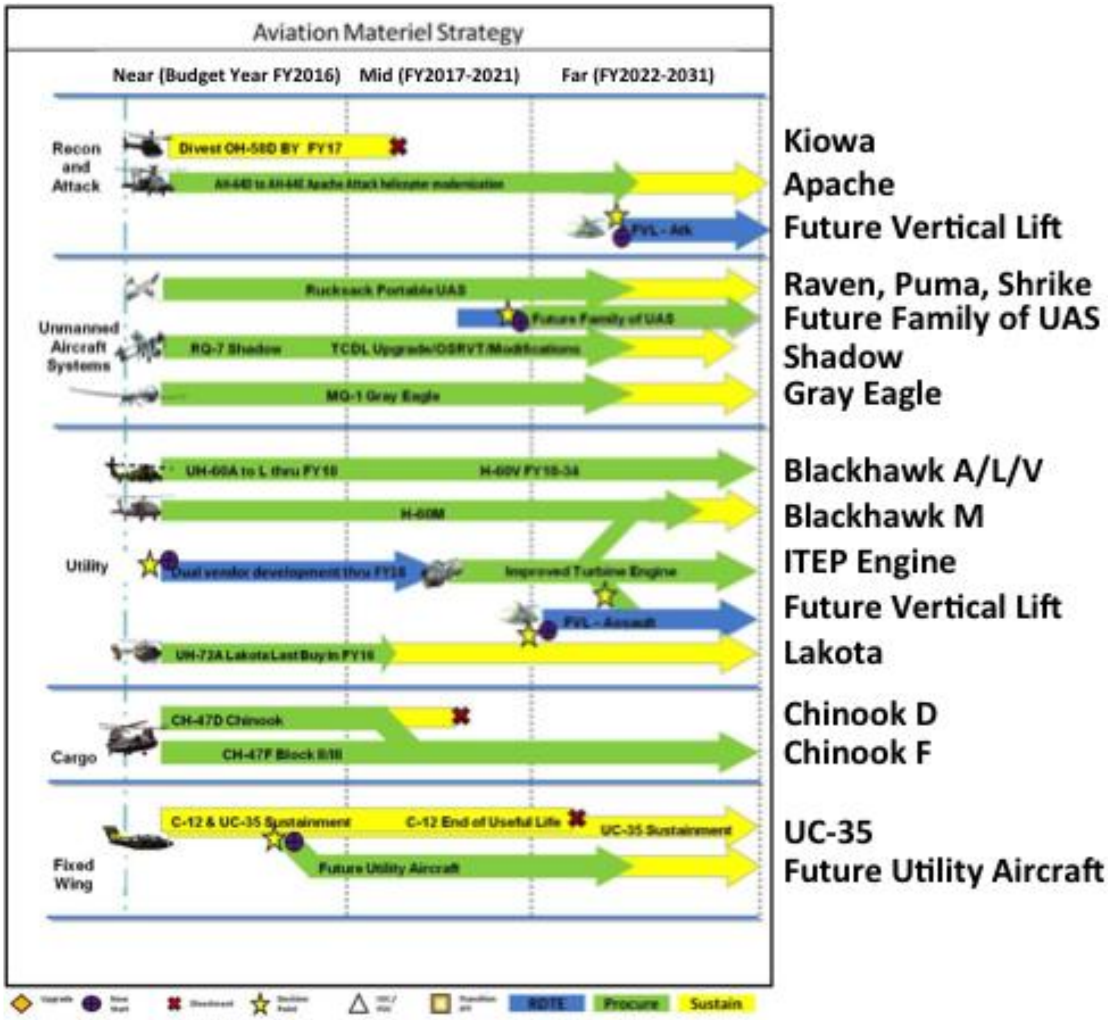
- ASA(ALT): Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …) as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1)

Figure 4-7. Findings and Recommendation Set #3

4.4 Modernization of Legacy Rotorcraft Systems

Army Aviation is continually faced with the challenge of trying to achieve an optimal balance of its R&D investments committed to modernizing/upgrading legacy rotorcraft platforms and developing new systems that offer expanded performance capabilities and reduced sustainment compared to current systems. The Future Vertical Lift (FVL) Family of Systems (FoS) represents the future of Army Aviation manned (and optionally manned) rotorcraft systems. FVL is currently an initiative within the Army Aviation S&T portfolio and is not expected to become a Program of Record (POR) until after the current Program Objective Memorandum (POM). Therefore, if the program were to follow normal DoD acquisition processes for an ACAT I Major Acquisition Program and the Planning, Programming, Budgeting and Execution (PPBE) processes, an Initial Operating Capability (IOC) for FVL would not be expected until the mid-2030s. After IOC, at historical Army Aviation procurement funding levels, it will take roughly 30-40 years to replace the legacy platforms.

It is expected, therefore, that legacy rotorcraft systems (AH-64, CH-47 and UH-60), which are all 1960-1970 vintage designs, will remain deployed until at least 2060. This century-long platform life would be rivaled only by the B-52 bomber, which has been re-purposed from its original mission to extend its utility. These Army rotorcraft platforms have undergone several upgrades over their lifetimes, and the Army plans to continue modernization of these platforms until FVL is deployed (Figure 4-8).



Source: Army Equipment Program in Support of President's Budget 2016.

Figure 4-8. The Army Plans to Retain Legacy Systems Far Into the Future

However, since it will take several decades of FVL procurement to replace all legacy platforms, at least one more major upgrade to these systems will be required beyond those currently in progress or funded within the POM for them to remain operationally effective against the evolving threat. Fortunately, several significant technology initiatives within the Army Aviation S&T portfolio apply to both legacy and future manned systems. These technologies include ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T. The RDECOM advanced aircraft engine program (see Figure 4-9) is a perfect example of the type of dual-purpose technology program that yields benefits to both future and legacy aviation systems. The operational utility of inserting ITEP/FATE engine technology into a legacy system is illustrated in Figure 4-10 by the dramatic increase in range/payload of the Black Hawk platform. The vertical dashed line (at a radius of 200 km) in the figure illustrates a doubling of payload capacity in transitioning from the current engine to the ITEP engine.

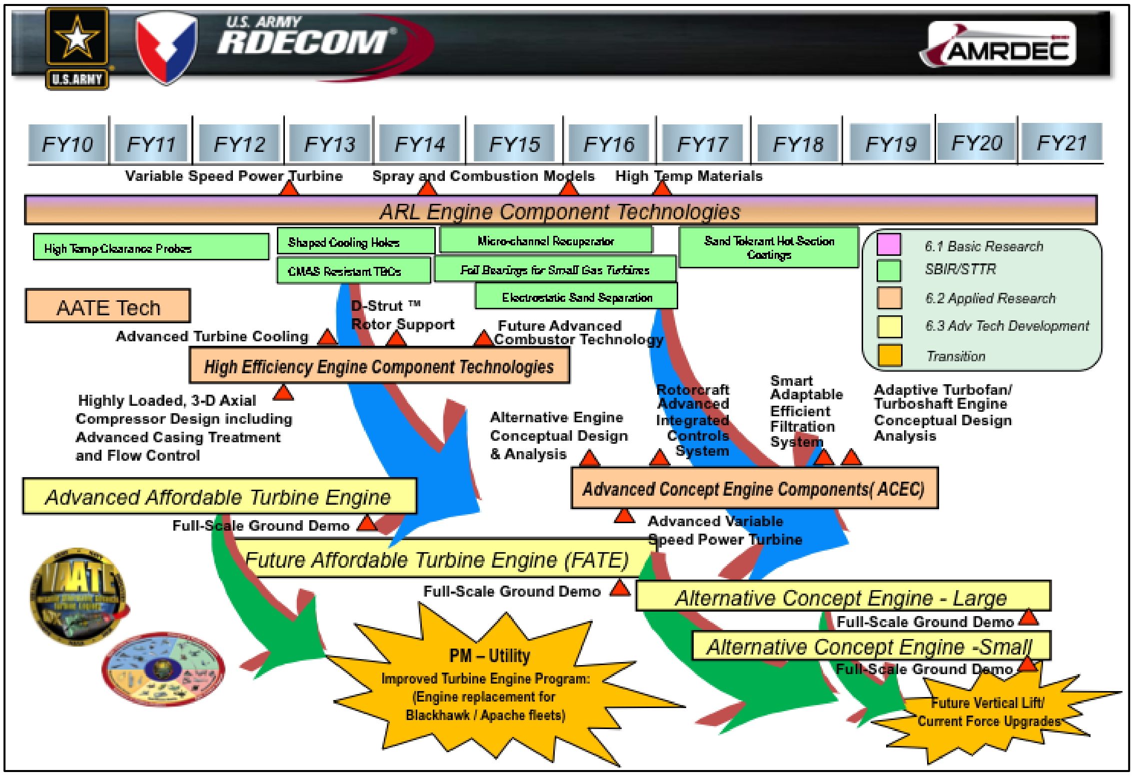


Figure 4-9. Army Aircraft Engine S&T Roadmap

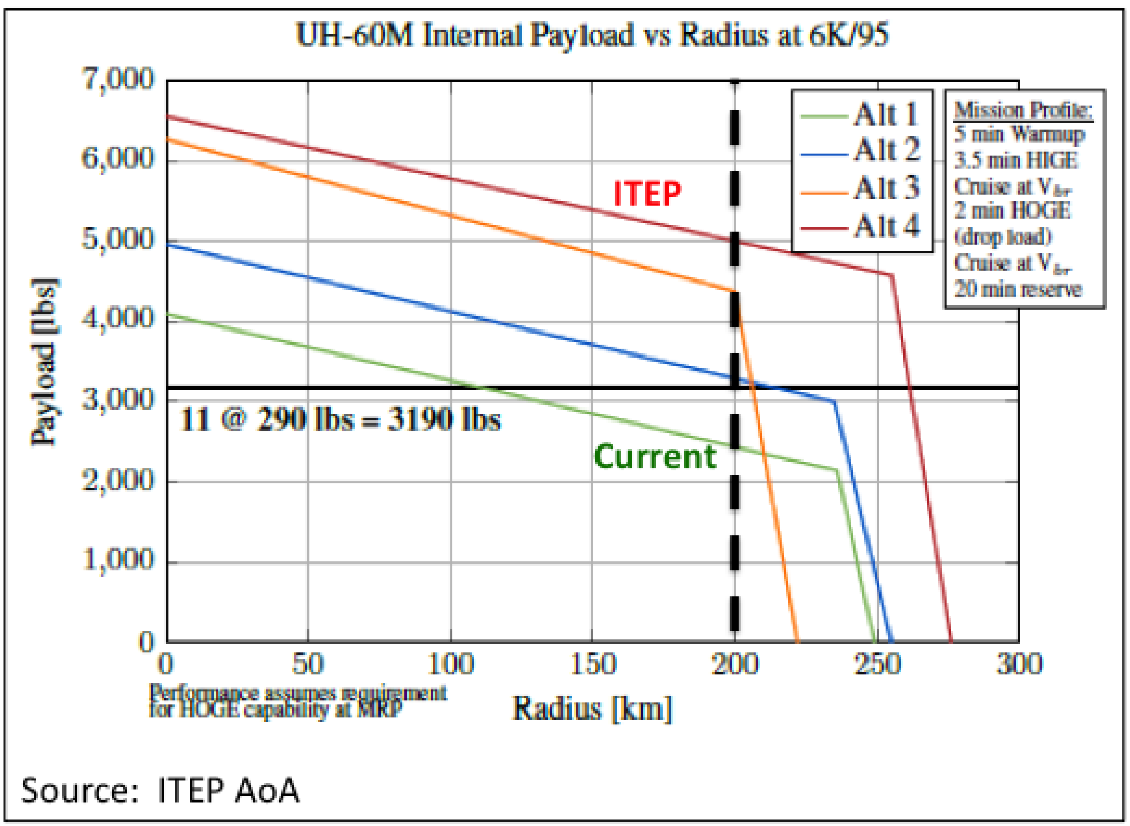


Figure 4-10. ITEP Provides Significant Improvement in Performance of Legacy Platforms

The recommendation resulting from these findings, detailed in Figure 4-11, is to continue S&T investment in dual use technology programs that benefit legacy systems as well as FVL.

Findings
- Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment.
- Within the current limited budget, Army Aviation S&T is investing in technologies that apply to both legacy and future manned systems.
- These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

Recommendation
- ASA(ALT): Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future aircraft, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).

Figure 4-11. Findings and Recommendation Set #4

4.5 FVL Acquisition with Speed and Simplicity

The current FVL schedule, which is driven by funding constraints as well as technology maturation, does not lead to an IOC of the *first FVL* variant (most likely the FVL-Medium replacement for either AH-64 or UH-60) until the mid-2030 timeframe (see Figure 4-12). After IOC, given anticipated procurement budget constraints, it will take a decade or two to replace the legacy system. It must be emphasized that this schedule applies only to the first FVL variant. Funding constraints will limit development, test and procurement of the second and third variants to later timeframes. The study team noted that an opportunity exists to perform an Analysis of Alternatives (AOA) between MDD in October 2016 and Milestone A in 2019. Flight data would be collected during this period to support the AoA.

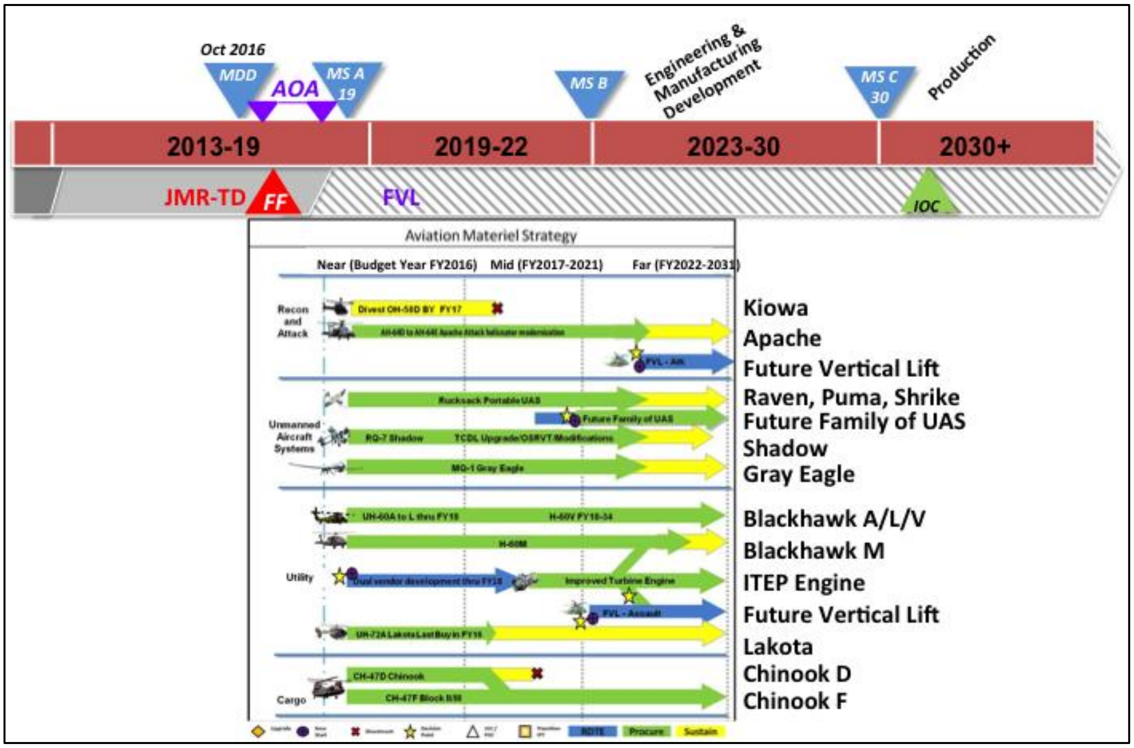


Figure 4-12. FVL – First Aircraft Timeline

Affordability of FVL is needed to deal with limited funding. Affordability, in turn, is driven by requirements. As the only new aviation program on the horizon, FVL will be pressured by the operational community to have system and performance requirements that satisfy every possible operational need. Lack of requirements discipline is one leading cause of acquisition program failure. FVL will be no exception if the requirements process is not tightly managed and constrained. An approved DoD acquisition process, known as evolutionary acquisition, could prove to be of great value in managing requirements growth and in accelerating the introduction of FVL into the fleet. Under this acquisition strategy, the operational and acquisition communities would agree on a set of objective performance requirements, but also agree on a more limited set of these objectives that could provide an effective early operational capability. Pre-planned capability upgrades leading to the full set of objective requirements would also be defined. Such an approach would help not only to manage requirements but also accelerate IOC for a limited capability.

Such acceleration, however, is dependent on technology maturity. In addition to unrealistic requirements and/or requirements growth, unrealistic evaluations of technology maturity is the other most significant cause of acquisition program failure. Fortunately for FVL, due to major industry investment, the JMR-TD demonstration vehicles will have greater fidelity and be more representative of the FVL-Medium operational design than would normally be expected. Parallel investments in the FACE/JCA open system architecture could provide the technology basis for some acceleration of a Milestone B DAB.

An acceleration of the FVL program would also be of significant benefit to the health of the US rotorcraft industry, which has eroded over the past several decades due to the lack of military development programs. It should be remembered that the backbone platforms of the Army rotorcraft fleet (i.e., UH-60, AH-64 and CH-47) are all essentially 1960-1970 vintage designs and developments. The decline of US market share in the commercial helicopter market provides evidence that US leadership in rotorcraft system design and development is eroding. As indicated in Figure 4-13, the total share of US industry *combined* is only 25%, while the two European companies, Airbus Helicopters and Augusta Westland, have almost 60% of the world market.

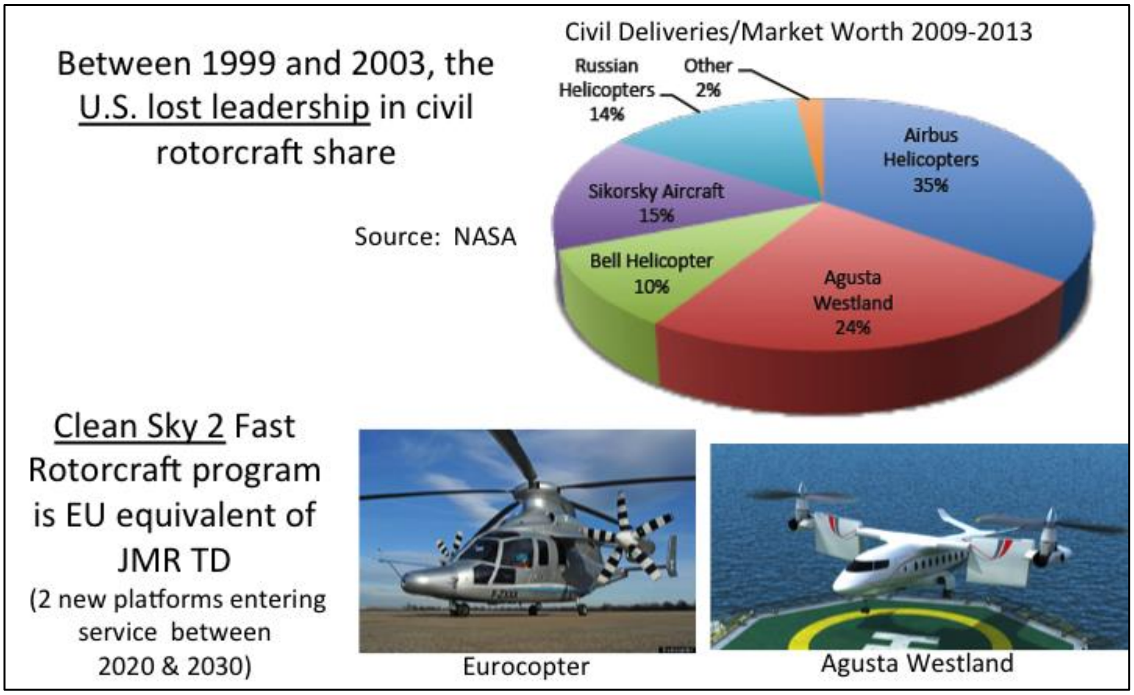


Figure 4-13. Worldwide Competition

Among the programs being sponsored by the European Union is the Clean Sky 2 Fast Rotorcraft Program, which has performance attributes similar to FVL and which is building two prototypes very similar to JMR-TD. A robust US rotorcraft industry is essential for the future of Army Aviation, but that is certainly not assured in this global environment.

These findings lead to the recommendation, detailed in Figure 4-14, that ASA(ALT) should develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding of a new rotorcraft consistent with budgetary realties.

Findings

- JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
- The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
- The current FVL schedule leads to an IOC of the first system in the mid-2030s. It <u>should be beneficial to accelerate</u> this timeline through an evolutionary acquisition approach if funding allows.
- The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Recommendation

- ASA(ALT): <u>Develop an evolutionary acquisition approach</u> for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Figure 4-14. Findings and Recommendation Set #5

4.6 Aviation Mission Systems

RDECOM has numerous S&T efforts ongoing at AMRDEC, CERDEC, ARDEC, and ARL aimed at improving the mission system capabilities of Army Aviation systems. The majority of these efforts focus primarily on manned aviation systems, either for upgrading legacy systems or toward providing the technology base for future systems (i.e., FVL). That balance extends across all areas affecting affordability and mission effectiveness (e.g., lethality, survivability, sustainability, and maintainability), as well as all subsystems (e.g., airframe, power, propulsion, sensors, avionics, secure communications and networks, weapons). A much smaller portion of the RDECOM S&T portfolio is dedicated to unmanned systems, including several projects that advance state-of-the-art of autonomy, compatible mission systems, and manned-unmanned teaming (see Section 3.3). Many of the S&T projects, however, while aimed primarily toward manned or optionally manned systems, in fact have dual applicability to unmanned systems as well. For example, much of the CERDEC sensor and ASE development work is equally applicable to manned and unmanned systems.

Of particular note for potential dual use is the Degraded Visual Environment (DVE) work being conducted by AMRDEC and CERDEC. Focused principally on providing the means for manned rotorcraft systems to operate safely in a variety of degraded visual environments (see Figure 4-15), the effort includes the development of modern control laws to improve flight control in legacy systems. These techniques can support automated flight modes that enable capabilities such as terrain and obstacle avoidance and automated safe landing modes also applicable to unmanned systems. In addition, one of the objectives of the project is to demonstrate multi-ship networking, illustrated in Figure 4-16, which could support the distributed functionality manned-unmanned teaming concepts previously discussed in Section 4.3.

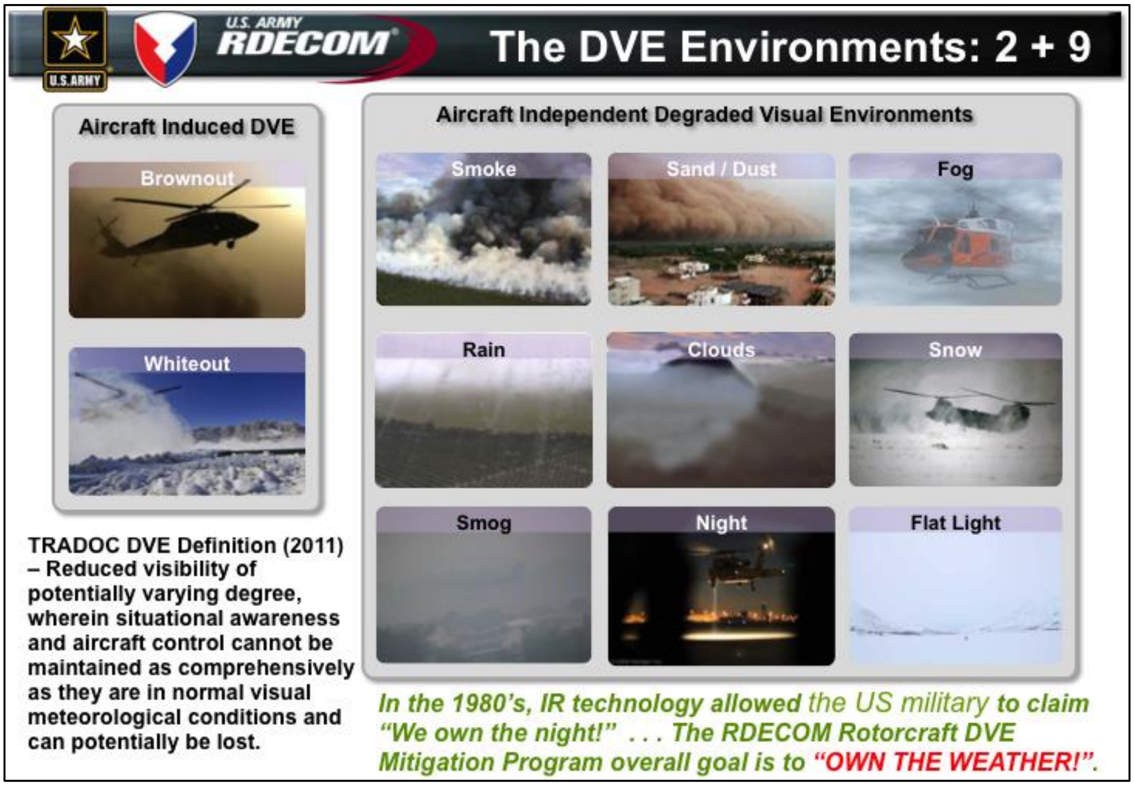


Figure 4-15. RDECOM DVE

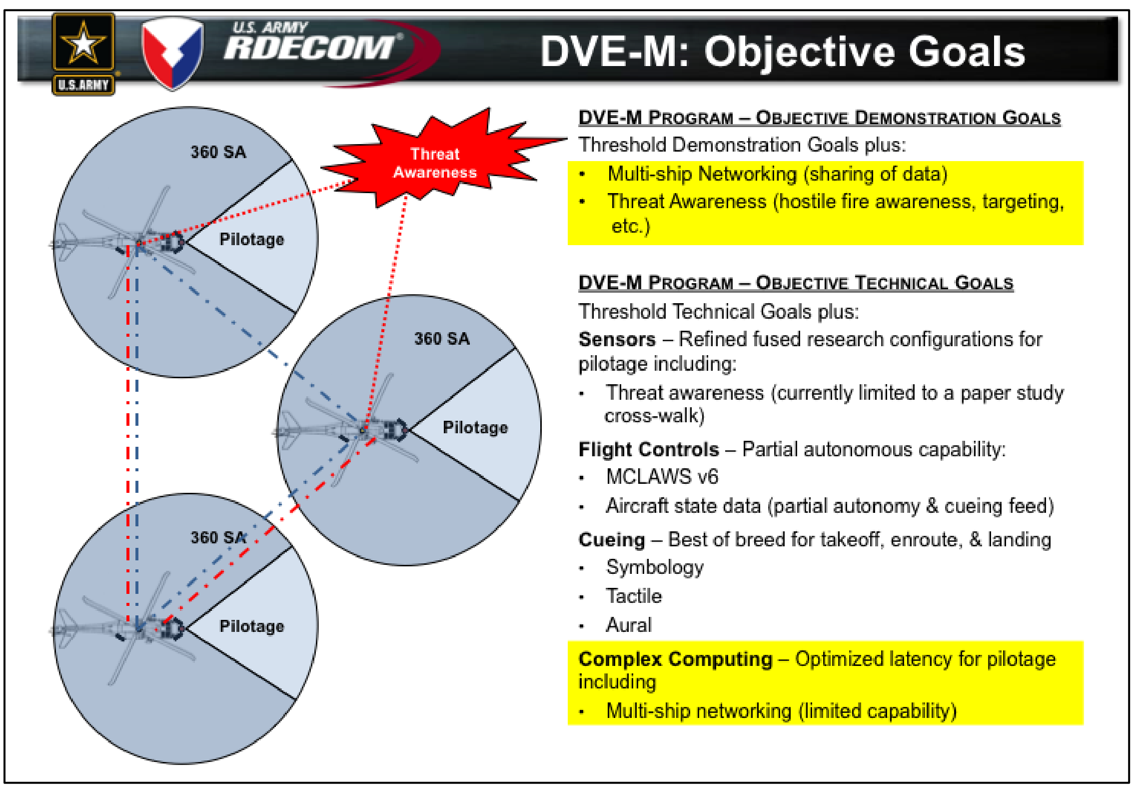


Figure 4-16. DVE-M Objective Goals

The mission systems work is vital to the future of Army Aviation and exploits much of the unique rotorcraft modeling, simulation and test facility capabilities that are resident within the Army S&T community by virtue of the Army's role as the DoD lead for rotorcraft systems. The recommendation in this area, included in Figure 4-17, is to expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Findings

- Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks.
- RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking.
- Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS).
- Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed.
- Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed.
- DoD provides singular modeling and wind tunnel capabilities (NASA Ames)

Recommendation

- AMRDEC/ADD: Expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation Set #1).

Figure 4-17. Findings and Recommendation Set #6

4.7 Aviation Systems Integration and Testbed

The system-of-systems concepts likely to emerge from the operational effectiveness analysis (Recommendation Set #1) will require an extensive modeling, simulation, experimentation and testing capability to validate operational utility, as well as to ensure that the system elements are well integrated. This capability requires an integrated aviation systems testbed, which may include M&S, laboratory prototype bench testing, operationally realistic prototype demonstrations, and SoS field experimentation in which elements interface and integrate under realistic operational conditions. Such an integrated testbed does not currently exist. However, some critical elements exist or are in development upon which the integrated capability could be built. The geographical distribution of these elements presents an integration challenge, which will rely on networking capabilities for real-time interaction when necessary.

Foundational to the testbed are the core capabilities resident within AMRDEC for the M&S, test and evaluation of rotorcraft systems. The AMRDEC and NASA wind tunnel facilities are national assets for both Government and industry testing of design concepts and validation of computer design/evaluation codes. The rapid prototyping capabilities within AMRDEC for flight demonstration and testing of advanced subsystems and components on rotorcraft test assets is also a critical element for an integrated testbed. It is also possible that the JMR-TD demonstration vehicles could be utilized for prototyping demonstrations after the JMR flight test objectives have been completed.

CERDEC has a variety of world-class laboratories for aircraft survivability testing and evaluation that are important elements of the integrated testbed. Among these are anechoic chambers, seeker countermeasures effectiveness hardware-in-the-loop facilities, and several aircraft survivability equipment laboratories. CERDEC has a future vision for holistic integrated air and ground survivability capability that would facilitate the development of system and system-of-systems applications that enable intelligent integration of survivability systems that would progress beyond platform centric survivability (see Figure 4-18) to system-of-systems solutions (Figure 4-19). The proposed Future Holistic Adaptive Survivability Technology (FHAST) project that would develop a state-of-the-art suite of integrated electronic warfare capabilities to protect air and ground platforms from emerging threats would be a significant step toward the integrated testbed capability.

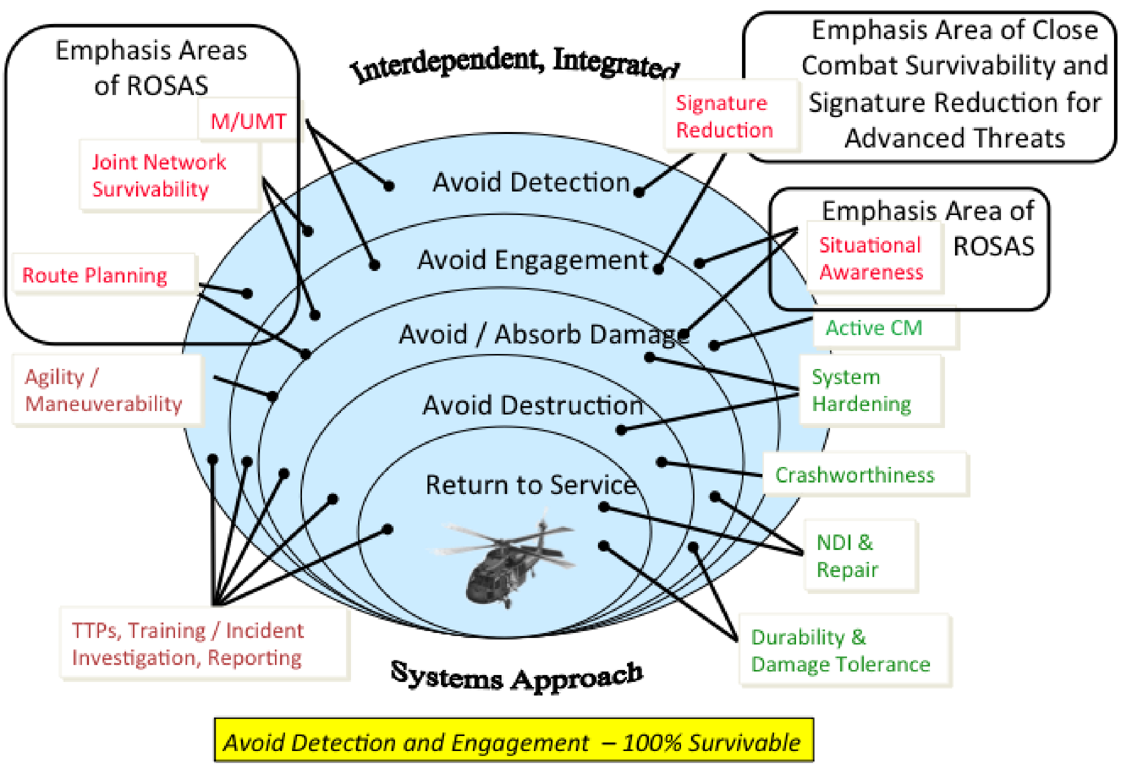


Figure 4-18. AMRDEC Total Survivability Paradigm – Platform-Centric

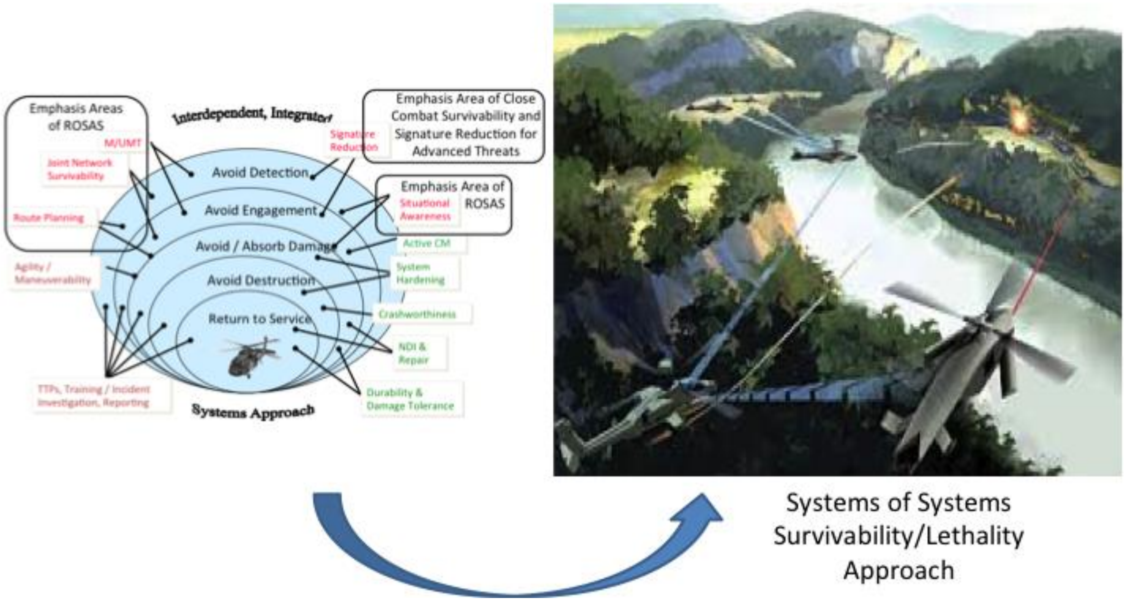
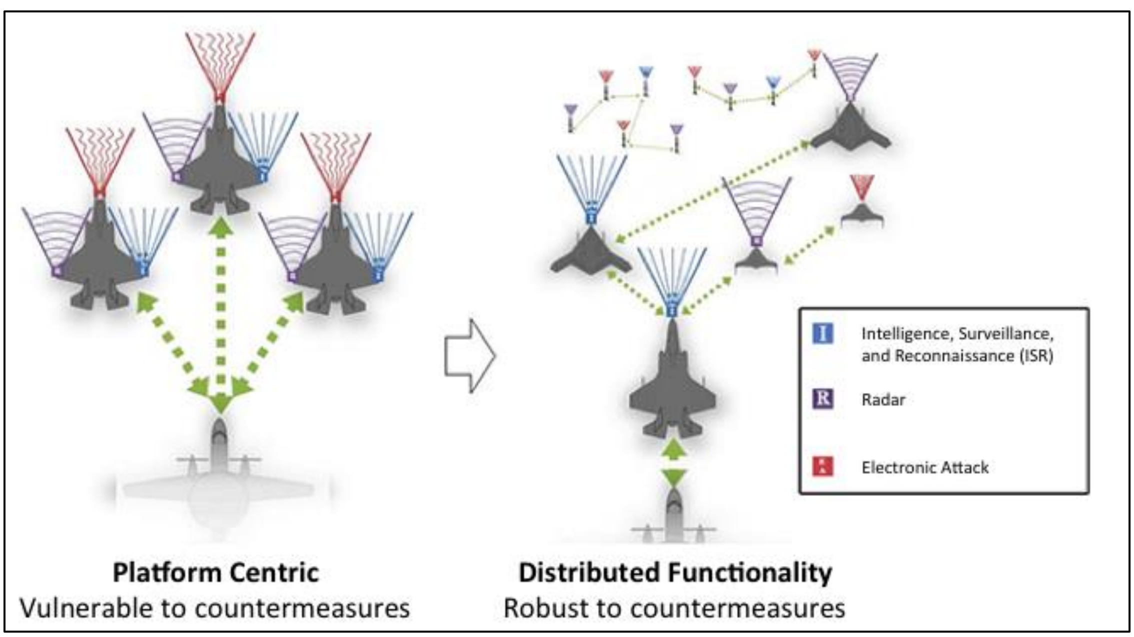


Figure 4-19. Total Survivability from System-of-Systems Perspective

DARPA can also contribute to the integrated testbed by means of its system-of-systems M&S capabilities that are being utilized to examine SoS concepts, such as the SoSITE project, illustrated in Figure 4-20.



Source: DARPA SoSITE Website

Figure 4-20. System of Systems Example

The recommendations emanating from these findings, detailed in Figure 4-21, are for RDECOM to pull together the building blocks to develop an integrated aviation testbed.

Findings

- Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing.
- Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE).
- Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.

Recommendations

- RDECOM: Build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comms, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations").
- RDECOM: Building on Recommendation 1 and Sections 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.

Figure 4-21. Findings and Recommendations Set #7

4.8 Advanced and Disruptive Systems S&T

Army Aviation is at a crossroads of opportunity and challenge – opportunities to be found in emerging technologies that will enable significant advances in aviation and challenges posed by technology advances and availability among our adversaries. In the current climate, information about many emerging technologies and new applications of technology is available to everyone with an Internet connection.

In order to leverage technological opportunities and avoid technological surprise, it is essential for Army S&T to address leap-ahead technologies that support Army Aviation. As illustrated in Figure 4-22, there are several areas of innovation currently being addressed, sometimes by other Services and agencies. For example, the DARPA X-Plane effort is evaluating new rotorcraft technologies to achieve higher speed, and numerous organizations, including the Army, are exploring directed energy options. The Navy is examining the utility of UAS swarms, and the Air force is investigating air-launched UAVs. The Army must ensure that it is positioned to incorporate new concepts having significant potential to improve platform performance and reliability as well as to exploit unmanned aerial vehicles and manned-unmanned teaming to full advantage.

In particular, a shift toward a formation of unmanned systems controlled by a manned aircraft offers significant promise toward reducing the overall risk and cost of selected missions. If single-purpose UAS (e.g., ISR, strike, electronic warfare, or comms) can be used as illustrated in Figure 4-23, each asset is less costly than if every platform is designed to perform all functions. Even if one asset is lost, the remaining assets can continue to carry out the mission.

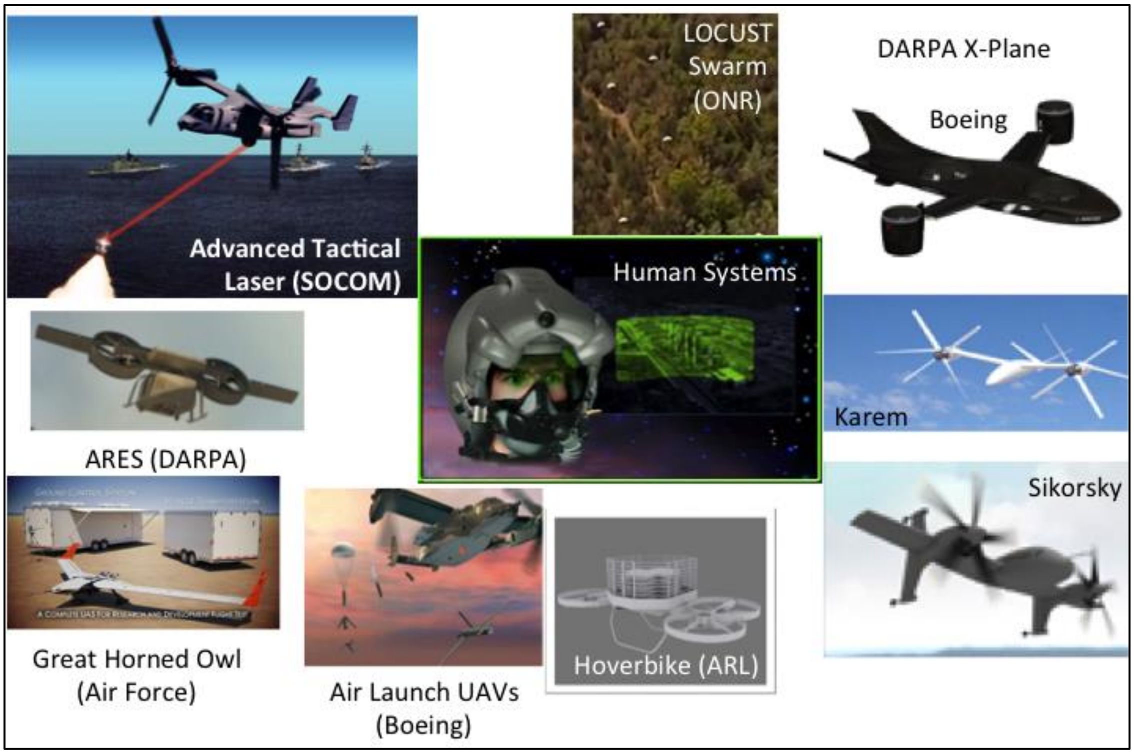


Figure 4-22. Aviation Innovation Examples

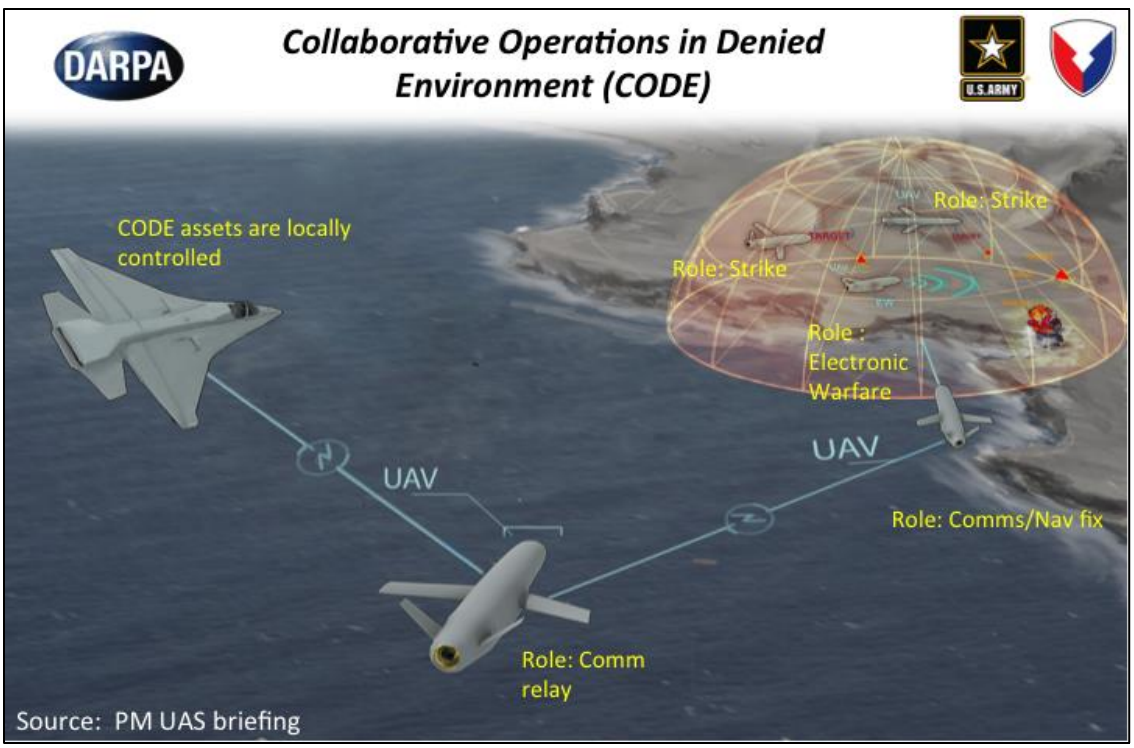


Figure 4-23. DARPA-RDECOM CODE Program

The ASB study team recommends that RDECOM develop advanced technologies for an integrated/ holistic manned/unmanned architecture/system to help ensure survivability and mission success. The team also recommends that ASA(ALT) include in its S&T portfolio appropriate leap-ahead technologies. The findings and recommendations on this topic are summarized in Figure 4-24.

Findings

- Army Aviation is at a crossroad of challenge and opportunity.
  - The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber).
  - The opportunity: technology is emerging that enables significant improvement in aviation capabilities.
- Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise.
- There is relevant work in other Services, DARPA, and NASA that should be leveraged.

Recommendations

- RDECOM: To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success.
- ASA(ALT): Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)

Figure 4-24. Findings and Recommendations Set #8

4.9 S&T Investment Strategy

One of the most successful Army Aviation development efforts has focused on improved turboshaft engines. The ITEP and FATE programs have led to improved engines that can be transitioned from S&T to programs of record for legacy systems, but they can also be incorporated in designs for future vertical lift. Maintaining active participation in engine development programs is key to achieving further advances and program transitions.

Most of the current Army investment in aviation technologies is focused on manned rotary wing platforms. If the manned-unmanned formations described above are to be evaluated and potentially implemented, S&T funding must be made available to develop the needed unmanned platforms and control systems.

As is documented in Appendix I, the Army Total Funding request in the FY2016 Budget Request is $147B ($126B Base and $21B OCO). Within the base budget, $16.1B is allocated for Procurement, with $5.7B for aircraft (34% of the total). In contrast, the total Army S&T budget request for Applied Research (Budget Area 2) and Advanced Technology Development (Budget Area 3) is $1.77B, with only $144M (8%) committed to Aviation projects. Thus only 8% of the BA2/BA3 budget request is expected to support 34% of the procurement request. This is not sufficient to meet the challenges discussed above.

According to data from the OSD Air Platforms Community of Interest (COI), the Army FY2016 request amounts to 64% of the DoD BA2/BA3 request for rotary wing aircraft. This is consistent with the Army's role as Lead Service for rotorcraft. The next largest contribution is from DARPA, largely for the VTOL X-Plane effort. NASA funding for rotorcraft is minimal ($20M). Thus the Army cannot rely on any other Government organization for significant rotorcraft development.

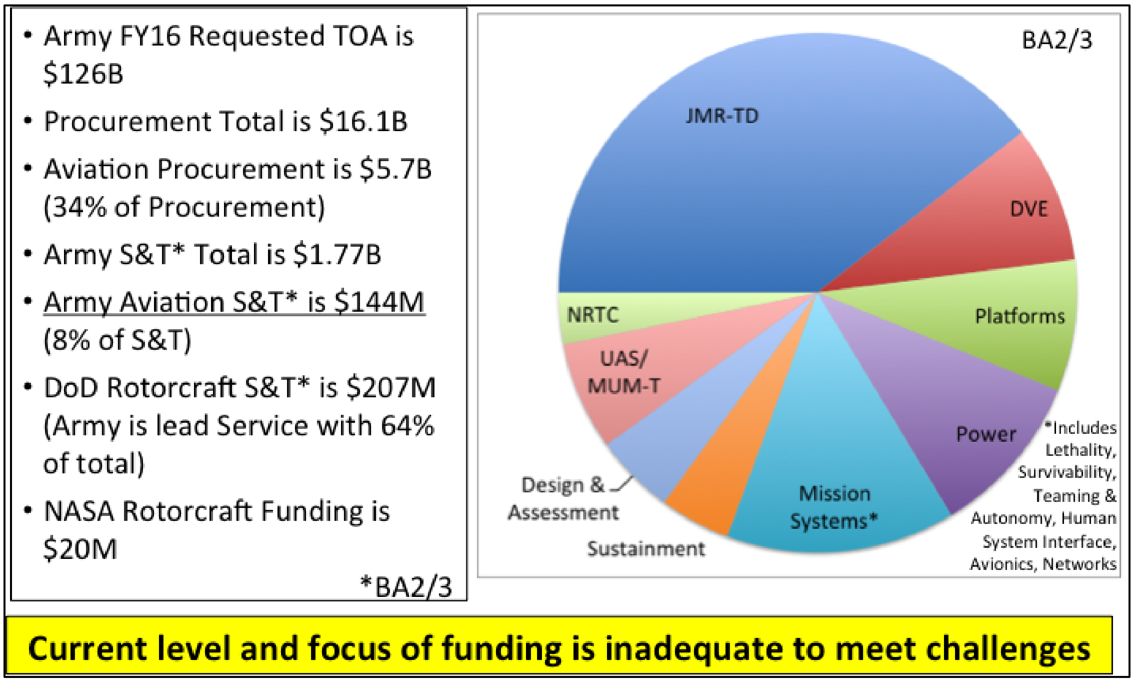


Figure 4-25. Meeting Future Challenges Demands a Robust Aviation Portfolio

One potential means to increase funding for aviation S&T is to employ innovative mechanisms for external collaboration with universities and industry. An example of such a mechanism is the DARPA Grand Challenge mechanism used to encourage development of autonomous ground vehicles. It is recommended that ASA(ALT) advocate for additional funding for Aviation S&T. Figure 4-26 provides a summary of findings and recommendations for this topic.

Findings

- Based on findings in Sections 1-8, the capabilities of Army Aviation S&T must evolve rapidly (e.g., need to expand UAS and autonomy activity); thus the level of S&T activity must expand beyond the manned aviation S&T portfolio, which is currently well managed.
- Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms.
- Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.

Recommendations

- AMRDEC/ADD: Continue active participation in VAATE and RAMPED engine development.
- RDECOM: Explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct).
- ASA(ALT): After exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

Figure 4-26. Findings and Recommendations Set #9

5 CONCLUSION – THE FUTURE OF ARMY AVIATION

This Army Science Board study examined options for the Future of Army Aviation in the 2025-2040 time period that were informed by (1) clear trends in the rapid global growth of technology; (2) numerous serious, increasing, and evolving threats; (3) more than 30 visits to various Government and non-governments facilities and forums; and (4) a review of some 500 documents. Based on this work, the study team concluded that a context was critical to identifying these technical and operational options.

The rate of change of technology in the 21st century presents both challenges and opprtunities. The study team looked at an approach to this rapidly evolving and uncertain environment that requires the development of a new architecture able to adapt quickly, is cost-constrained, takes advantage of advancing technology, applies integrated systems thinking, and ultimately provides needed warfighting capability. This "System of Systems" construct (a way to describe different approaches that employ capabilities from the ground and air) provides for future capabilities, not only for airborne assests, but also for ground and air warfare. In this context, the study team's first and most important recommendation is that "Systems of Systems Operational Effectiveness Analyses" must be conducted to help identify the needs for Army Aviation. These analyses will inform many of the remaining recommendations.

The study team has strongly recommended increased emphasis on unmanned aircraft systems (UAS) with appropriate use of autonomy in conjunction with, and complementary to, human capabilities. The ISR focus of current UAS, with some limited attack capability, can and should be rapidly expanded. It is the human-machine system optimization that provides flexibility and affordable new capability in tomorrow's fight. Consistent with an evolving character of warfare and potential new roles for Army Aviation, our people in this Human-Machine System will need new systems operations/management skills and capabilities to deploy Army Aviation in the future Joint fight. For example, helicopter pilots would have a greater role in directing a "formation" of air assets, only some of which have soldiers in them.

Intellectual capital and innovation would be hallmarks of this adaptive system. Modularity of "system" design and deployment would allow increased speed of adaption and affordability. The potential exists to provide needed capability in a rapidly changing environment through the use of more, relatively inexpensive "parts" that are quickly integrated into increasingly dynamic and tailorable complex systems. Thus, Army Aviation capability is derived more from the "system of systems" rather than from the individual "parts" or platforms. The attributes of the "system" outlined in this report include implementing a "cost-imposing strategy" on the adversary, plus affordable speed of adaption to new and uncertain environments and to new technical and operational oportunities.

As presented in the study team's concluding briefing chart below, the threats are rapidly changing, the character of warfare is changing, and Army Aviation must change too. Thus, to win in a complex aviation world, the study team believes that an Aviation Systems of Systems approach is necessary. This approach must be pursued with urgency.

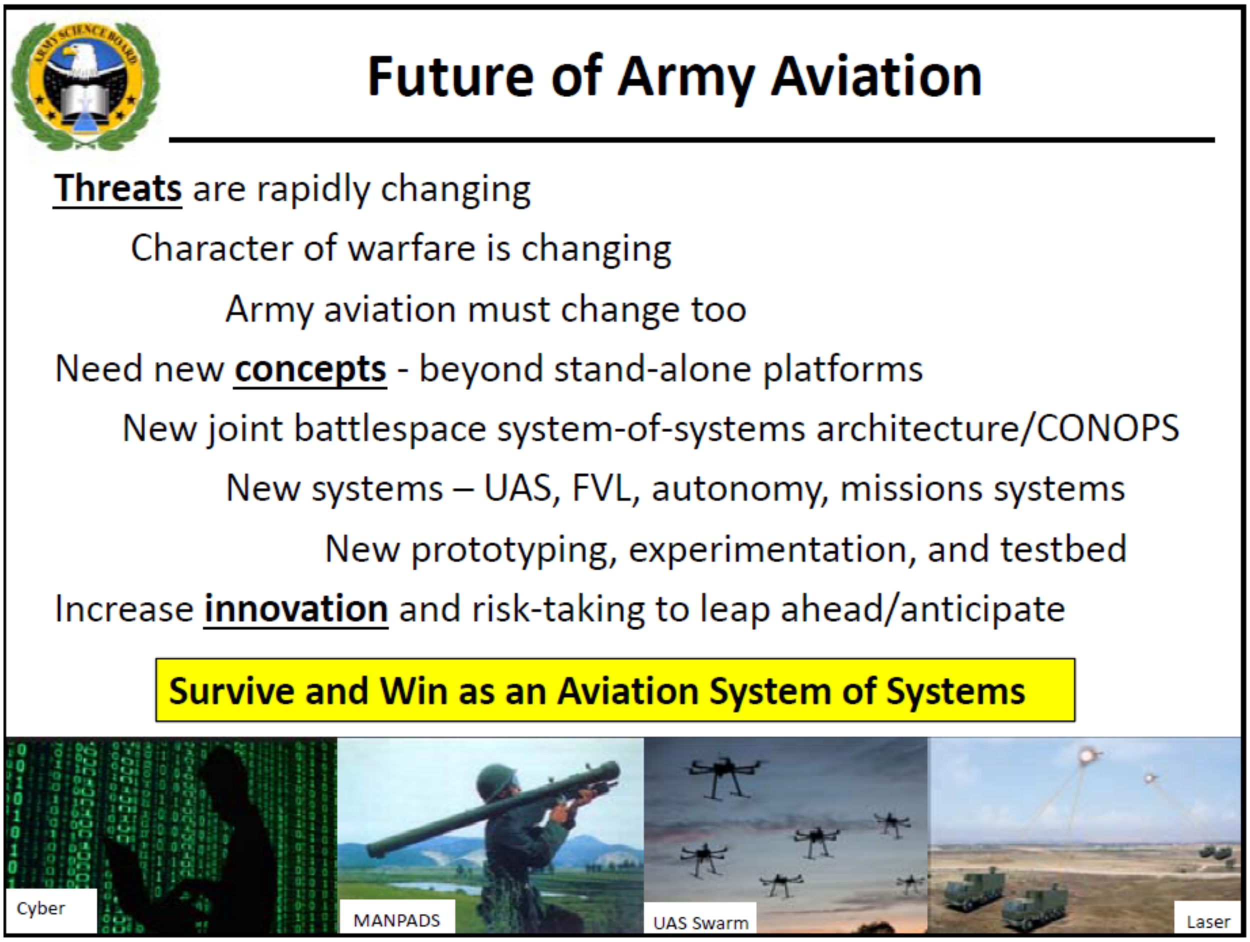


Figure 5-1. Future of Army Aviation

APPENDICIES

APPENDIX A TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON

JAN 06 2015

Dr. James Tegnelia
Chairman, Army Science Board
101 Army Pentagon
Washington, DC 20310

Dear Dr. Tegnelia:

I request that the Army Science Board (ASB) conduct a study entitled "Army Science and Technology for Army Aviation 2025-2040."

Analysis of the future Army operating environment suggests that under the current investment strategy, the Army will retain technology advantages to the end of this decade. After 2020 the Army will begin to experience erosion of overmatch, and between 2030 and 2040 the Army can expect to lose the edge in several key areas. To meet these challenges, aviation must address today's needs while balancing investments in innovation to enable next-generation aviation capabilities.

The objective of the study is to identify and assess Science and Technology (S&T) enhancements capable of being fielded during the 2025-2040 timeframe that will increase Army Aviation's expeditionary capabilities to support full-spectrum military operations and reduce its sustainment tails and logistics footprint. The study should:

a. Review current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T plans, modernization plans and ongoing developments, as well as relevant Force 2025 and Beyond Campaign activities.

b. Address the use of innovative technologies that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply.

c. Include, but not necessarily be limited to, the following key focus areas for improvement: (1) near-zero maintenance platforms and systems, (2) exploitation of unmanned aircraft systems, (3) meeting the challenges of emerging threats and (4) enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.

d. Determine the feasibility and risks associated with each of the findings and recommendations.

The G-3/5/7 is the sponsor of this study and will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs. The ASB shall present a comprehensive briefing that describes the study methodology and includes all findings and recommendations to the G-3/5/7 and me by September 30, 2015. The final written report shall be provided by October 31, 2015. All data supporting study findings and recommendations shall be available to Army senior leaders upon request.

The study will be conducted in accordance with the Federal Advisory Committee Act and DoD Directive 5104.4, "DoD Federal Advisory Committee Management Program." It is not anticipated that this study will need to go into any "particular matters" within the meaning of Title 18, United States Code Section 208, nor will it cause any member to be placed in the position of acting as a procurement official.

Sincerely,

John M. McHugh

John M. McHugh

APPENDIX B STUDY TEAM MEMBERS

The 2015 ASB Army Science and Technology for Army Aviation 2025-2040 study consisted of the following members and support staff:

Dr. Ron Sega (Maj. Gen. - Ret) (Chair)

Dr. Mark Glauser (Vice Chair)

Dr. Nancy Chesser

Mike Heinz

Grant Hollett (RADM - Ret)

Tom Ramos

Teresa Smith

Dr. Bill Snowden

Dr. Alan Willner

Red Team Advisor: George Singley

Study Manager: Maj Andy Brown

APPENDIX C SITE VISIT AND INTERVIEW LINES OF INQUIRY

Army Aviation S&T Home on Home / 22-23 January 2015 / Ft. Rucker, AL

- ASB Team members observed at meeting of Army organizations

Meetings of Future Vertical Lift IPTs / 17-19 February 2015, 28-29 April 2015, 23 June 2015 / WBB, Reston, VA

- ASB Team members observed at meetings of FVL IPTs

Aviation Development Directorate Industry Day / 3 March 2015 / AMRDEC, Huntsville, AL

- ASB Team members observed presentations to industry

Aviation Development Directorate / 16 March 2015 / NASA Langley Research Center, VA

- ASB provided TOR and asked for input on topics therein

Aviation Development Directorate / 17 March 2015 / Ft. Eustis, VA

- ASB provided TOR and asked for input on topics therein

Aviation Development Directorate / 19-20 March 2015 / NASA Ames, CA

- ASB provided TOR and asked for input on topics therein

Army Aviation Association of America – Army Aviation Mission Solutions Summit / 30-31 March 2015 / Nashville, TN

- ASB Team members attended the Quad-A Summit

Aviation Development Directorate / 1-2 April 2015 / Huntsville, AL
Specific Lines of Inquiry:

1. What do you consider to be ADD's core competencies?
2. Why was ADD's Advanced Systems and Concepts Office eliminated?
3. What is expected to be the next breakthrough in rotorcraft and why is it a game changer?
4. The 2007 DSB report on VSTOL aircraft supported by the SecDef cited a number of deficiencies in DoD rotorcraft programs, including in the areas of survivability, vulnerability, flight and crash safety, crew cognitive overload, and reliability. What actions has ADD taken and what progress has been made in response to the report? What remains to be done, and are the requisite resources and technological opportunities available?
5. How do ADD activities leverage technological developments of the Special Operations Aviation (SOA) community?
6. Does Army Aviation have a propulsion RDA roadmap? How important is ITEP? To what extent are ITEP and the JMR Tech Demo scalable for FVL?
7. How do ADD personnel and programs interface with ARL, PM ASE, PEO Aviation, PEO IEWS, PM UAS, NASA, and DARPA?

8. What advanced/innovative concepts and technologies under development within ADD can be expected to contribute to the CSA's Force 2025 and Beyond Campaign being led by CG TRADOC?
9. What are ADD's principal contributions to the JMR Tech Demo and FVL programs?
10. What are the upper and lower limits of the scalability of JMR Tech Demo to smaller and larger rotorcraft?
11. Have design concept synthesis and assessment studies been conducted to evaluate alternative design options (e.g., tilt-rotor, compound or hybrid concepts) against the capability needs and performance goals of each class of the FVL FoS, as documented in the FVL FoS ICD (April 2013) and the JFTL ICD (October 2009)? What conclusions can be reached regarding the best fit of each concept to each class?
12. Has the robustness of each design concept to requirements creep or changes been studied? Robustness in this context means low sensitivity of the design gross weight and performance to requirements changes (e.g., payload weight/size, mission equipment SWAP, threat capability or countermeasures, etc.) during full scale development. What conclusions can be reached?
13. Has the life cycle cost for each FVL class (including Ultra) been evaluated? Please provide best LCC estimates at this time. What is the estimated cost savings for each class if designed from the outset as an unmanned system instead of a manned or optionally manned system?
14. Which performance objectives from the FVL FoS ICD and the JFTL ICD are the most challenging for each class of FVL? Which objectives, if tailored, would result in the greatest benefit from vehicle size, overall capability and cost standpoints? Which are the most challenging from a technology development standpoint for each class?
15. How applicable are the technologies to be embedded in the JMR Tech Demo to the other classes of FVL (other than Medium)? Which JMR technologies are also good candidates for transition to rotorcraft Programs of Record? What percentages of AMRDEC BA2 and BA3 R&D efforts are devoted to JMR?

<u>PEO Aviation / 1-2 April 2015 / Huntsville, AL</u>

Specific Lines of Inquiry:

1. The 2007 DSB report on VSTOL aircraft supported by the SecDef cited a number of deficiencies in DoD rotorcraft programs, including in the areas of survivability, vulnerability, flight and crash safety, crew cognitive overload, and reliability. What actions have been taken and what progress has been made in response to the report? What remains to be done, and are the requisite resources and technological opportunities available?
2. What specific technologies were inserted in the latest block upgrades to the AH-64, UH-60 and CH-47? What improved system and operational capabilities were fielded as a result of these block upgrades? What was the total investment associated with each of these upgrades?
3. Are any additional upgrades planned for these rotorcraft? If so, what technologies and capabilities advances are part of these plans? What funding is in the POM to initiate these upgrades?

4. What is your assessment of the ability of the latest or planned upgrades of AH-64, UH-60 and CH-47 aircraft to effectively perform their missions against evolving threats over the next 20-30 years?
5. What additional unplanned and/or unbudgeted technology insertions and/or block upgrade improvements would have the greatest positive impact on mission effectiveness over the next 20-30 years?
6. Are there any technologies in development for the JMR Tech Demo program that would be good candidates for insertion into the AH-64, UH-60 or CH-47?
7. What is your assessment of the current Army Aviation portfolio and the VCSA portfolio review process? What were your top priorities not fully funded in the current Army Aviation portfolio?
8. Does the Army have an operational architecture, systems architecture, and technical architecture for its current and future fleet of unmanned aerial systems?
9. In the last 10 years, what technologies or advanced products developed/sponsored by DARPA have been incorporated in Army Aviation? What is your assessment of the current DARPA VTOL program?

<u>USAACE, TCM Lift, TCM UAS, USAARL, Safety Center / 2-3 June 2015 / Ft Rucker, AL</u>

- ASB provided TOR and asked for input on topics therein

<u>Operational Support Airlift Agency / 5 June 2015 / Ft Belvoir, VA</u>

- ASB provided TOR and asked for input on topics therein

<u>National Aeronautics and Space Agency (NASA) / 9 June 2015 / NASA HQ, Washington DC</u>

- ASB provided TOR and asked for input on topics therein

<u>Night Vision and Electronic Sensors Directorate (NVESD) / 9 June 2015 / Ft Belvoir, VA</u>

- ASB provided TOR and asked for input on topics therein

<u>DARPA TTO / 10 June 2015 / Arlington, VA</u>

- ASB provided TOR and asked for input on topics therein

<u>Army Research Laboratory / 10-11 June 2015 / Adelphi, MD and Aberdeen Proving Ground, MD</u>

- ASB provided TOR and asked for input on topics therein

<u>Intelligence and Information Warfare Directorate (I2WD) / 11 June 2015 / Aberdeen Proving Ground, MD</u>

- ASB provided TOR and asked for input on topics therein

<u>Industry Representatives and Vertical Lift Consortium / 24 & 26 June 2015 / Arlington, VA</u>

- ASB provided TOR and asked for input on topics therein

<u>Naval Air Systems Command and PM Aviation / 25 June 2015 / Naval Air Station, Patuxent River, MD</u>

- ASB provided TOR and asked for input on topics therein

<u>Air Force Research Laboratory / 7 July 2015 / US Air Force Academy (USAFA), Colorado Springs, CO</u>

- ASB provided TOR and asked for input on topics therein

APPENDIX D JOINT MULTI-ROLE TECH DEMO AND FUTURE VERTICAL LIFT INITIATIVE

Future Vertical Lift (FVL) Family of Systems (FoS) is an initiative (not yet a program) to develop a family of rotorcraft for the United States Armed Forces. Originally four different sizes of aircraft were to be developed. They are to share common hardware such as sensors, avionics, engines, and countermeasures. The precursor for FVL is the Joint Multi-Role (JMR) Technology Demonstration (TD) program, which plans to demonstrate relevant technologies in 2017.

D.1 Joint Multi-Role Technology Demonstration (JMR-TD)

The Joint Multi-Role Technology Demonstration (JMR-TD) is a 50/50 cost sharing initiative between the Army and vendors. JMR-TD is **NOT** a prototype for Future Vertical Lift – it is a technology demonstration. Four vendors were selected in October 2013 to begin designing a vehicle demonstrator:

1. AVX Aircraft Company – coaxial-rotor, ducted-fan compound helicopter
2. Bell Helicopter, a Textron Company – tilt rotor
3. Karem Aircraft Inc. - variable-speed tilt rotor
4. Sikorsky Aircraft – Boeing Company – coaxial rigid-rotor, pusher-propulsor design

Figure D-1 Phase 1 JMR-TD Designs

In August 2014 the competitors were down-selected to two, Bell and Sikorsky-Boeing, to build demonstrators for 2017 flight. Details of those designs are shown in Figure D-2 and Figure D-3. The remaining two competitors, AVX and Karem, have been funded for technology development.

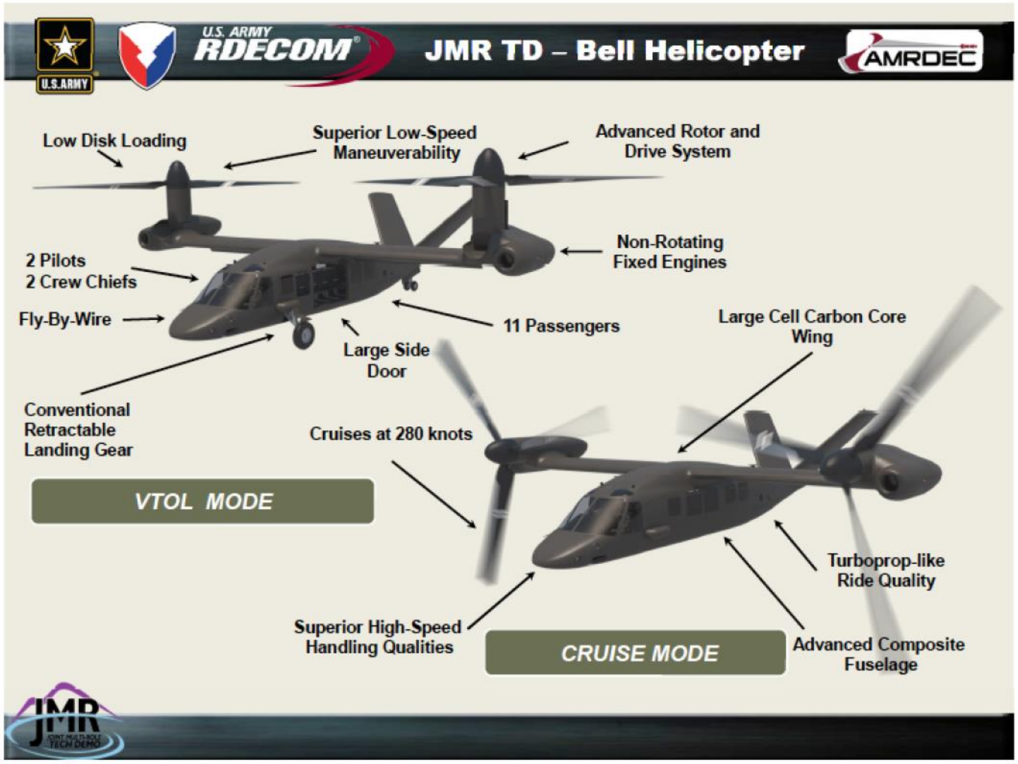


Figure D-2 Bell Helicopter JMR-TD Design

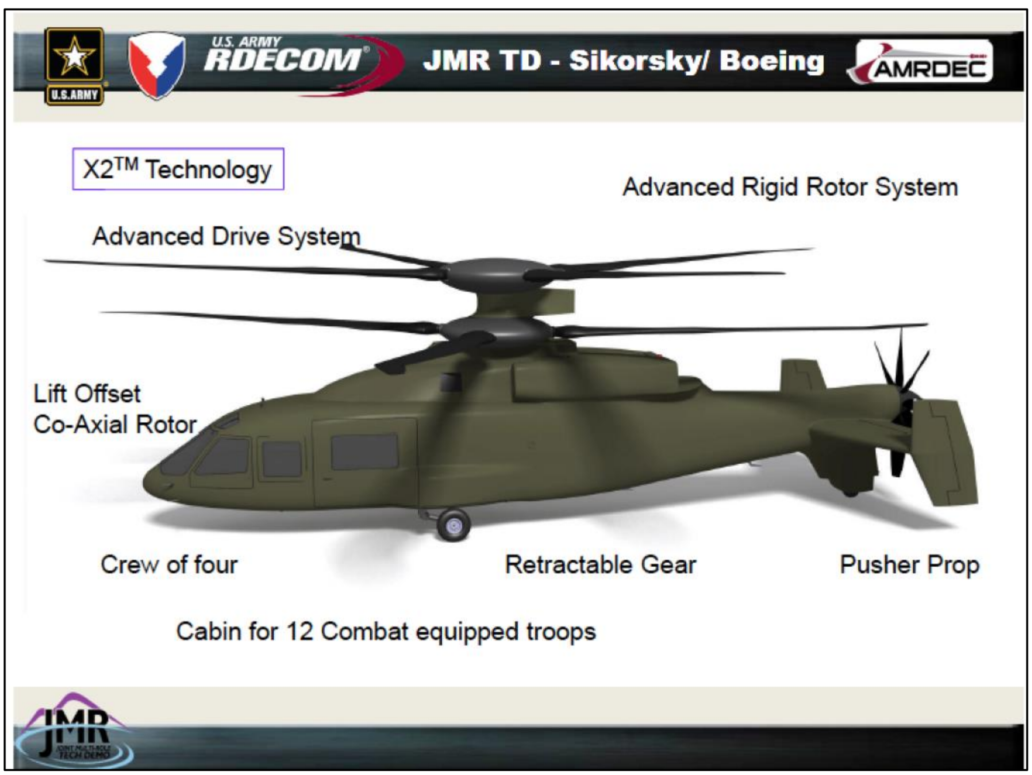


Figure D-3 Sikorsky/Boeing JMR-TD Design

Both vehicles use existing engines (the CH-53 engine for Bell and the CH-47 engine for Sikorsky-Boeing).

The schedule for the JMR-TD is shown in Figure D-4. The Air Vehicle Demonstration (AVD) at the top of the figure will enable learning with regards to

- Advanced technology implementation on high speed air vehicle configurations
- The refinement of analytical methods for coaxial and tilt rotor configurations
- The collaboration of the rotary wing enterprise to provide an advanced, efficient, affordable aviation weapon system

Because it is too early to design a mission equipment package (MEP) or mission systems architecture for FVL, the Mission Systems Architecture Demo (MSAD) shown at the bottom of the figure will focus on standards, processes and tools to support the FVL.

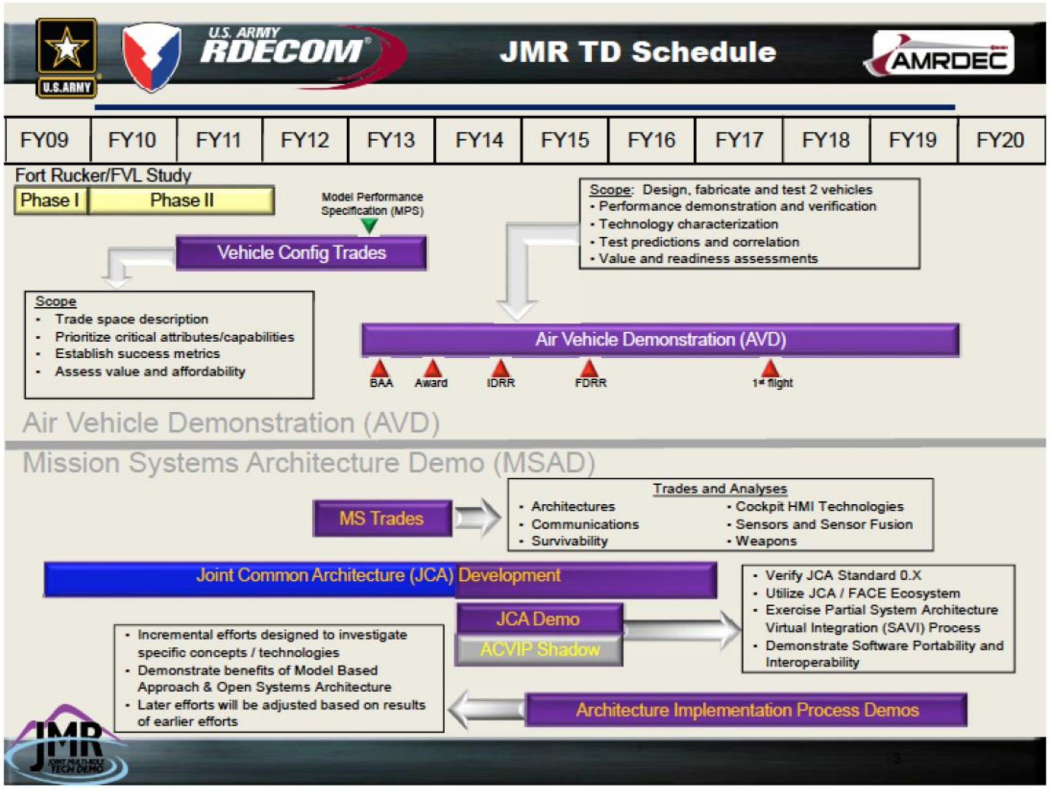


Figure D-4 JMR-TD Schedule

D.2 Future Vertical Lift (FVL) Family of Systems (FoS)

Because the current FVL initiative will presumably lead to a development effort, and perhaps a procurement effort, much of the information obtained by the study team is competition sensitive and will not be included here.

The FVL FoS initiative is a multi-service effort led by the Army. To ensure coordination between the JMR-TD and FVL efforts, Dan Bailey at AMRDEC is the Program Director for both. The figure below shows the multiple Integrated Product Teams (IPTs) involved in scoping the FVL effort.

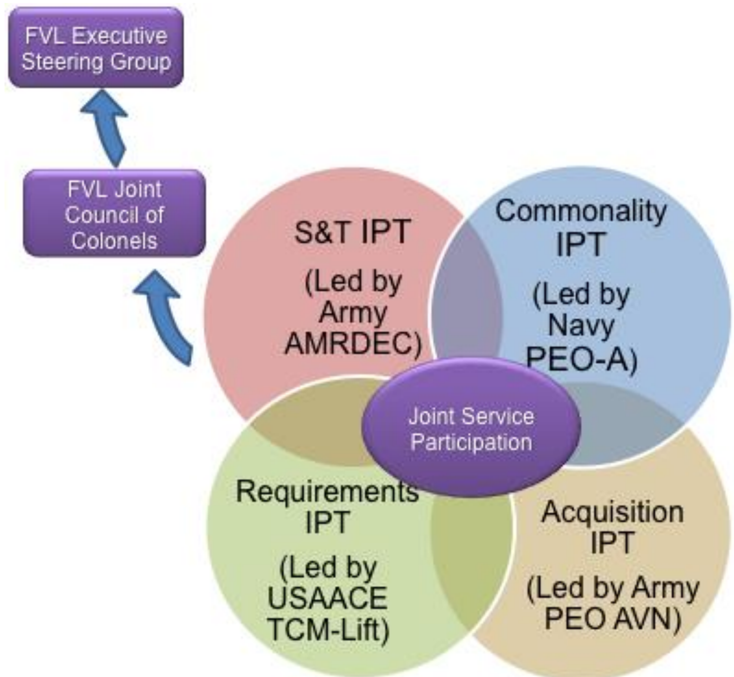


Figure D-5 Multiple IPTs Support the FVL Initiative

The duties of the individual IPTs are:

- Requirements IPT (RIPT) – will develop official requirements documents
- Acquisition IPT (AIPT) – will develop documents to support the acquisition process
- Commonality IPT (CIPT) – addresses use of common systems across FVL
- S&T Overarching IPT (SOIPT) – will develop S&T strategy for FVL (has 12 Working IPTs)
    - Air Vehicle Platform
    - Propulsion
    - Communications & Navigation
    - Weapons & Fire Control
    - Survivability & Vulnerability
    - Sensors: Pilotage & Targeting
    - Human System Integration
    - Mission Management
    - Vehicle Management / Flight Controls
    - Reliability & Maintenance
    - Subsystems
    - Training

The objective of the S&T OIPT is not to design an airplane but rather to identify technologies that might be available. FVL is NOT an airplane program – it is an initiative to develop an aviation weapon system (thus weapons WIPT etc. above).

Although requirements are still being refined, the notional concept for a new aircraft must:

- Reach speeds of 230 knots (260 mph; 430 km/h)
- Carry up to 12 troops
- Operate in "high-hot" conditions at altitudes of 6,000 ft (1,800 m) and temperatures of 95-degrees Fahrenheit,
- Have a combat radius of 424 km (263 mi) with an overall unrefueled range of 848 km (527 mi).

As is shown in Figure D-6, technology assessment for FVL takes place in the JMR Technology Demonstration. Capabilities Assessment at the top of the figure shows the major documentation that must be developed for an acquisition program. Note the anticipated Materiel Development Decision is October 2016 and Milestone A is January 2019.

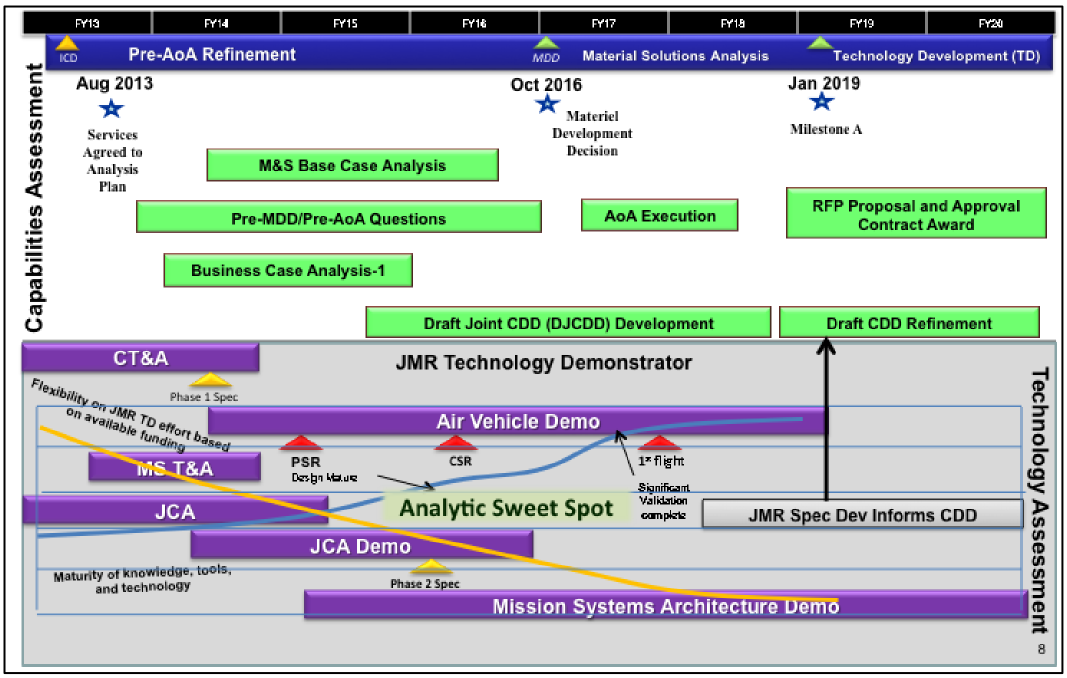


Figure D-6 Projected Road Ahead for FVL

Mission sets considered in the capabilities assessment include: cargo; utility; armed scout; attack; humanitarian assistance; medical evacuation; anti-submarine warfare; anti-surface warfare; land/sea search and rescue; special warfare support; vertical replenishment; airborne mine countermeasures; and others.

As is shown in Figure D-7, three sizes of aircraft are anticipated with one set of missions and potential Service customers for the light vehicle, three for the medium vehicle and one for the heavy vehicle. Additional details are competition sensitive.

The FVL family of aircraft will be required to have either optionally piloted or autonomous flight capabilities.

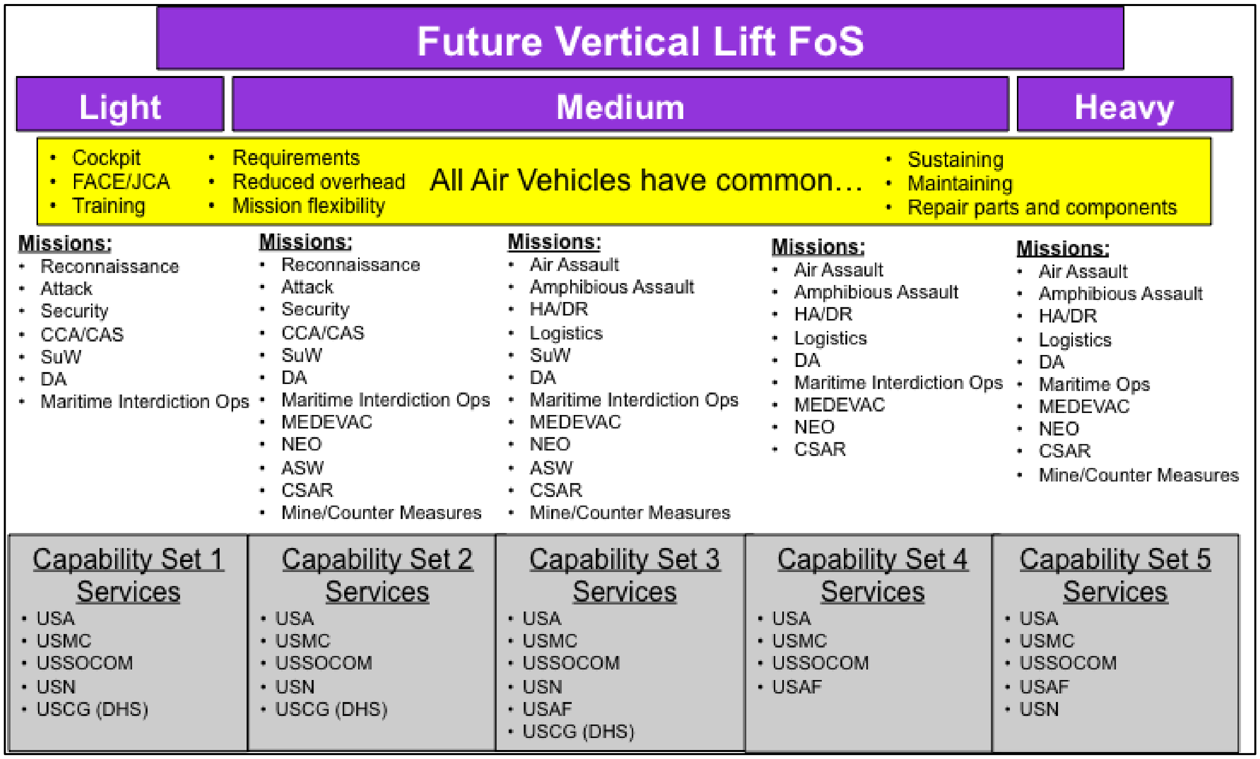


Figure D-7 The Future Vertical Lift Family

D.3 Findings Regarding JMR-TD and FVL FoS

The study team had several key findings with regard to JMR-TD and FVL FoS:

1. JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
2. The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
3. The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows.
4. The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Based on these findings, the team recommended that ASA(ALT) develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses recommended elsewhere in this report.

APPENDIX E ARMY AVIATION EFFORTS

The Aviation Development Directorate (ADD) is responsible for aviation S&T within the Aviation and Missile Research Development and Engineering Command (AMRDEC). Figure E-1 shows the organization of ADD. For the most part the Aviation Applied Technology Directorate (AATD) is located at Joint Base Langley-Eustis in Virginia, the Aeroflightdynamics Directorate (AFDD) is at NASA Ames Moffett Field in California, and the remainder of the organization is at headquarters at Redstone Arsenal in Alabama.

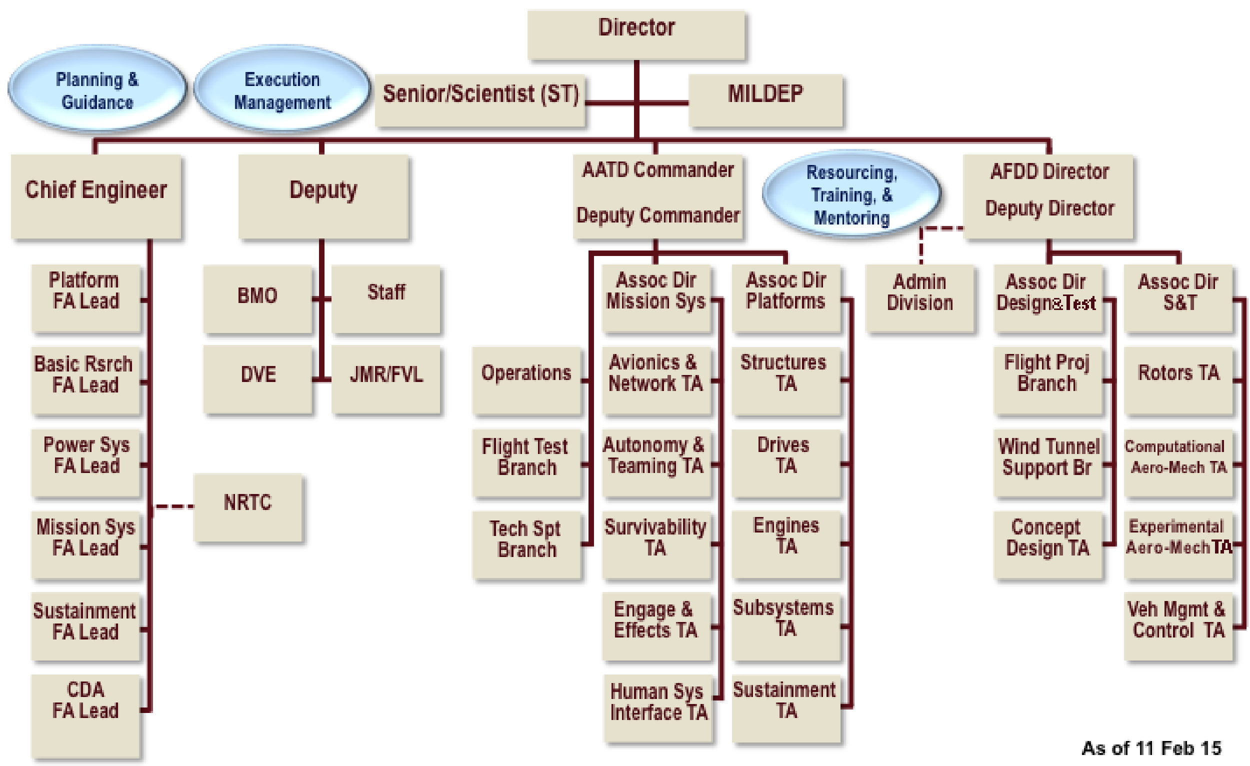


Figure E-1 Organization of the Aviation Development Directorate.

Figure E-2 shows the technology areas (TA) included in five of the ADD Focus Areas (FA). The sixth FA is Basic Research. Within these focus areas there are two major programs:

- Degraded Visual Environment Mitigation (DVE-M) in Mission Systems (see Section 3.1)
- Joint Multi-Role Technology Demonstrator (JMR-TD) in Platforms (see APPENDIX D)

- **Platform**
  - Aeromechanics / Rotors
  - Structures
  - Vehicle Mgt & Control
  - Subsystems
  - Vulnerability Reduction
- **Mission Systems**
  - Engagement and Effects
  - Survivability
  - Autonomy & Teaming
  - Human-Systems Interface
  - Avionics & Networking

Power
- Engines & Motors
- Other Power Sources
- Drives & Power Transmission

Operations Support and Sustainment
- Sustainment
- Flight Operations

- **Concept Design and Assessment**
  - Aerial System Concepts Evaluation
  - System Effectiveness

Figure E-2 ADD Focus Areas and Technology Areas

The Platform and Power Focus Areas were described in Section 3.5 in the Main Report. Mission Systems are described in Section 3.3 (manned-unmanned teaming) and Section 3.4 (lethality and survivability). The remaining focus areas are described below.

E.1 Operations Support and Sustainment

Programs in FY2016 Budget Documents

The Army's longstanding commitment to reducing maintenance costs and maximizing the performance and availability of aircraft, ground vehicles, and weapon systems is reflected in a wide range of RDT&E activities relevant to Condition-Based Maintenance (CBM) cited in the Fiscal Year 2016 Justification Book of Research, Development, Test & Evaluation, Army, Volumes 1-5.

For Budget Activity 1, Basic Research, specific efforts relevant to CBM involve research in the areas of advanced propulsion and structures. **Advanced Propulsion** efforts include work to develop thermal materials for advanced high-performance engines to reduce engine and transmission friction losses, improve performance, and reduce maintenance costs; on thermo-mechanical fatigue of materials; and on high-speed thermo-mechanical turbomachinery and mechanical energy transfer for future rotorcraft. It also includes development of advanced computational damage models and mechanical diagnostics experiments to improve the understanding of failure progression and diagnostics in drive train mechanical components, such as gears and bearings.

Advanced Structures basic research efforts include development of improved tools and methods to enable and enhance structural health monitoring capabilities and CBM for both rotorcraft and ground vehicles. It also includes work on composite structures able to meet the dynamic interaction requirements of future platforms identified by the Army Modernization Strategy. Overall, the research is intended to lead to safer and more affordable systems having extended service life, reduced maintenance costs, enhanced durability, and reduced logistics footprints. The work involves structural integrity analyses and development of failure criteria and inspection methods that address fundamental technology deficiencies in both metallic and composite Army rotorcraft structures. It addresses an urgent need for improved structural analysis and validation methods to predict durability and damage tolerance of composite and metallic rotorcraft structures, and the need for advanced structural dynamics modeling methods for both rotating and fixed system components important to future aircraft reliability. Specific efforts are focused on advanced fatigue assessment methodologies for metallic structures, improved composites technology, developing damage progression models, assessing the practicality of damage-detection sensing modes, failure mechanisms, integrated stress-strength-inspection, and advanced methods for predicting rotor system vehicle vibratory loads and aircraft stability.

Applied Research (Budget Activity 2) relevant to Condition Based Maintenance for aircraft builds on advances being recorded in ongoing basic research efforts. **Platform Design & Structures Technologies** efforts include the development and application of modeling and simulation tools to design and perform analysis of the Family of Systems (FoS) for Future Vertical Lift (FVL) to support "Zero Maintenance" helicopter concepts; physics of failure modeling to improve reliability of system components and enable damage-tolerant component design; and investigation of methods for monitoring component loads. Planned work for FY 2016 will include the development of improved damage initiation and propagation models, application of modeling and simulation tools to support design of FVL/novel concepts, and investigation of high-strain capable, multifunctional structures that offer improvements in structural efficiency and enable ultra-reliable, operationally durable designs.

Applied research in the area of **Maintainability & Sustainability Technologies** seeks to develop prognostic and system health assessment technologies to enable an enhanced CBM supportability structure applicable to an ultra-reliable, low-maintenance approach to aircraft design that significantly reduces unscheduled maintenance, inspections, and operations and sustainment costs. This work includes development of embedded multifunctional sensors with built-in processing and communications, health assessment systems to support adaptive controls, technologies for component self-assessment, and usage tracking and embedded history. Plans for FY 2016 call for investigating wireless communication technologies, integrating health assessment technologies into the Joint Common Architecture (JCA)/avionics/cockpit, developing fly-by-wire with CBM monitoring capability, developing miniaturized wireless sensors with on-component processing, history and parts tracking, and investigating technologies for in-flight transmission of condition/performance data to ground.

Applied research in the **Rotor and Structure Technology** area is directed toward the development of improved tools and methodologies enabling more accurate design for improved component reliability and durability. Specific efforts involve prognostic and diagnostic (P&D) inspection experiments aimed at improving structural risk assessment, development of self-sensing strategies for monitoring damage precursors, incorporating optimized sensing strategies into P&D systems, and investigating novel approaches for improving rotorcraft vehicle maintainability. FY 2016 plans call for the design and development of smart materials that can self-sense, self-heal, and self-reconfigure to facilitate damage/health assessment of aviation component structures, evaluation of material/component damage sensing strategies, modeling and simulation of damage detection, and investigation of data-fusion techniques for assessing material/component failure in aircraft.

Aviation Component Failure Modeling efforts include development of failure analysis and prediction models and techniques to support the Army's "zero maintenance helicopter" concept, including improved failure models to characterize and categorize specific material damage precursors relevant to aviation components, and a probabilistic framework for predicting remaining useful life of vehicle platforms. The work also includes investigation of advanced aviation component health monitoring techniques into health-usage monitoring systems (HUMS) and development of self-sensing structural material technologies that incorporate damage precursor detection philosophy. Planned FY 2016 work will develop the Virtual Risk-informed Agile Maneuver Sustainment (VRAMS) concept, which will evaluate technologies to autonomously provide state awareness at the material level and automate stress-reduction methods; investigate a "virtual reality" concept for self-diagnostics of real-time material state and automated solutions for self-directed maneuver alternatives in real-time; this effort will enable fatigue-free and zero-maintenance aircraft components. **Engine and Drive Train Technology** work includes development of high-temperature materials and improved methods for predicting propulsion system mechanical behavior.

Advanced Technology Development (Budget Activity 3) work relevant to Condition Based Maintenance for aircraft involves efforts in areas similar to those being pursued in basic and applied research projects. The **Advanced Rotary Wing Vehicle Technology** project includes activities intended to mature, demonstrate, and integrate components, subsystems and systems for vertical lift and unmanned air systems that provide reduced maintenance and sustainment costs and enable greater performance through improved rotors, drives, vehicle management systems and platform design and structures. Systems being demonstrated include rotors, drive trains, robust airframe structures, and integrated threat protection systems. This project includes the Joint Multi-Role (JMR) Technology Demonstrator in support of the Future Vertical Lift (FVL) family of aircraft.

Maintainability & Sustainability Systems work is focused on improving the operational availability of rotorcraft while reducing operating and support (maintenance) costs. Specific efforts include component sensing, diagnostics, prognostics, and control systems developments. The *far-term* objective of this work is to enable transition to an ultra-reliable, low-maintenance design approach that significantly reduces unscheduled maintenance, inspections and operating and sustainment costs. Recent and ongoing work has focused on advanced prognostic algorithms for failure modes for engines, structures, rotor systems and drives; the interfaces for health monitoring systems to communicate with Joint Common Architecture standards; integration of system health monitoring with electronic controls to enable adaptive control systems; engine adaptive controls to optimize performance, component life and maintenance schedule based on engine health; multifunctional aircraft sensor technology; demonstrating technologies for assessing the structural integrity of a primarily composite airframe; and verifying the integrity of composite repairs and predicting remaining useful life. FY 2016 plans include efforts to demonstrate wireless sensors for on-component processing of part health and usage history; evaluate methodologies enabling probability-of-failure predictions based on vehicle current state and anticipated missions; and mature and demonstrate technologies for component self-assessment, usage tracking and embedded history. Additional work will involve developmental testing of system health and fault recognition algorithms, sensors, and structural global health models. Advanced Technology Development work directed toward maturing integrated CBM technologies that reduce the operation and sustainment costs of vehicle electronics and electrical power devices is being conducted as part of the Army's **Combat Vehicle Electronics** project.

Ongoing RDT&E work in Budget Activities 4 and 5 is more limited than in the other categories, reflecting the fact that much work remains to be done before comprehensive CBM will become common practice for many Army systems. A search of ongoing activities in the Advanced Component Development and Prototypes (Budget Activity 4) category indicates only that the Aviation/Advanced Development program supports an **Advanced Maintenance Concepts and Equipment** project that includes work to develop diagnostics/prognostic monitoring systems. Activities supported in the System Development and Demonstration (Budget Activity 5) category include support under the **Aircraft Avionics** program for the Aircraft Notebook (ACN), an Army aviation automated information system program for streamlining the completion of aviation maintenance activities and the documentation required to maintain airworthiness for all Army aircraft. ACN reduces the information technology footprint within an aviation unit by integrating multiple software applications, including CBM+ tools, onto one hardware platform. The **Automatic Test Equipment** program includes a **Diagnostics/Expert Systems** project that supports the development of test and diagnostic systems and procedures, as well as integration of the Army's Maintenance Support Device (MSD), into the Brigade Combat Team information structure. The MSD serves as the at-platform data collection device for the Army's condition-based maintenance plus (CBM+) initiative and maintains compatibility with emerging aviation platform hardware bus technology, and ACN software interface requirements.

Revised Programs

Certain changes have been made to ARMY RDT&E activities involving CBM since publication of the Fiscal Year 2016 Justification Book of Research, Development, Test & Evaluation, Army, Volumes 1-5. The thrust of Applied Research (Budget Activity 2) involving **Maintainability & Sustainability Technologies** was changed in June 2015 to more accurately reflect work being done on the Autonomous Sustainment Technologies for Rotorcraft Operations (ASTRO) and Ultra Reliable Design programs. The work now involves continuing development of technologies and methodologies to enable more efficient designs and reduce the maintenance burden for future and current fleet vertical lift aircraft; development of on-engine, adaptive engine controls to optimize performance, component life and maintenance schedule based on engine health; development of in-flight, real-time, automated methods to adjust rotor system track and balance to reduce aircraft vibration and loads; development of improved failure detection capabilities within the planetary system; and reducing the size and weight impact of advanced sensor technologies. Additional work involves continuing development of methodology to allow operations above maximum continuous rating for limited periods of time; development of a level of autonomy for the condition assessment process for a composite airframe; decision support for repair decisions with a repair integrity assessment approach; and development of a comprehensive integrated aircraft-wide electrical system capability for diagnostics, fault isolation, and generating trendable health indicators. An assessment directed toward development of reliability criteria for design tools, methodologies, and materials to facilitate optimization of future rotorcraft designs is also being conducted.

Another change, one involving Advanced Technology Development (Budget Activity 3) in the area of **Maintainability & Sustainability Systems,** restates FY 2016 plans as emphasizing the development of technologies and methodologies to enable more efficient designs and reduce the maintenance burden for future and current fleet vertical lift aircraft. Specific planned activities include completion of developments of on-engine, adaptive engine controls to optimize performance, component life and maintenance schedule based on engine health; development of in-flight, real-time, automated methods for adjusting rotor system track and balance to reduce aircraft vibration and loads; development of improved failure detection within the planetary system; and reducing the size and weight impact of advanced sensor technologies. Additional planned FY 2016 work will develop methodology to allow operations above maximum continuous rating for limited periods of time; complete development of a level of autonomy for the condition assessment process for a composite airframe; and provide decision support for repair decisions with a repair integrity assessment approach. This change was also made to more accurately describe the work being done on the ASTRO program.

E.2 Concept Design and Assessment

The Concept Design and Assessment (CD&A) group focuses on

- Multi-disciplinary design analysis and optimization
- Development of design methods and tools
- Concept formulation and design
- Generation of conceptual design performance data to populate the evaluation trade space
- Evaluation of concepts' ability to meet user requirements
- Identification of technology impacts

Figure E-3 summarizes CD&A activities.

CD&A supports in-house AMRDEC efforts, JMR and FVL initiatives, next generation UAS efforts, and other efforts within the Aviation S&T community.

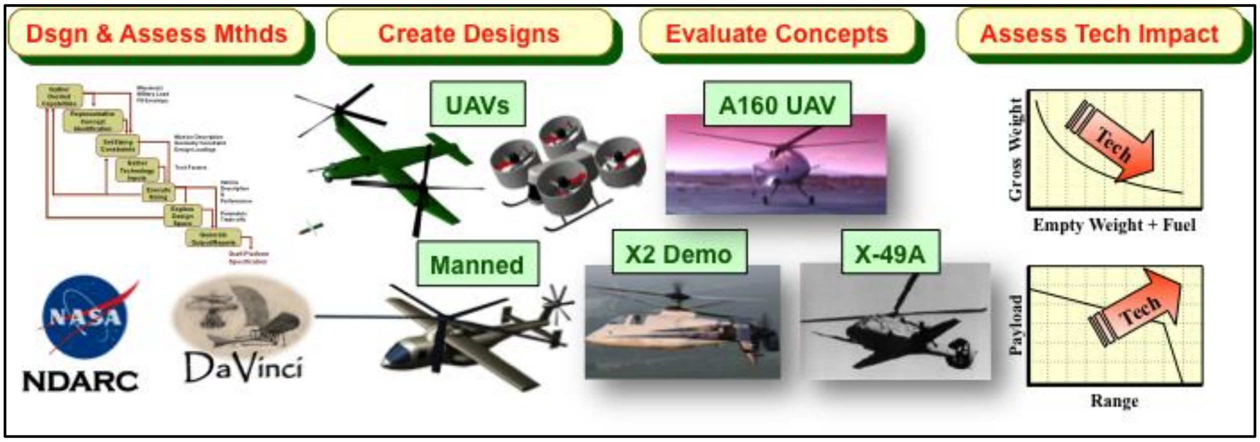


Figure E-3 CD&A Activities

For example, the group has performed extensive analysis for the Future Vertical Lift Initiative to explore the impact of various design choices on projected vehicle performance. These studies inform the requirements definition process to balance requirements across the family of systems. Assessments include aerodynamics, aeromechanics, performance, and flying qualities

In addition, in order to exercise current capabilities, develop new capabilities, and explore new concepts, the group also performs a "deep dive" on an advanced concept such as the tail sitter UAV configuration examined during FY15.

This is a small group (10-15 personnel) that acts as the "honest broker" for many efforts, comparing alternatives and independently assessing claims. Because many of these assessments are competition sensitive they cannot be discussed in this document.

E.3 Unmanned Aircraft Systems

Army Unmanned Aircraft System (UAS) efforts include Manned-Unmanned Teaming (described in Section 3.3) as well as development and modernization of UAS. This section focuses on the latter.

Legacy Army UAS include:

- Raven – hand-launched, 4 lb max takeoff
- Puma – hand-launched, 13.5 lb max takeoff
- Shadow – short range tactical ISR, 375 lb max takeoff
- Gray Eagle – Predator upgrade, 3,600 lb max takeoff

Figure E-4 lists the UAS challenges and concerns cited by the Deputy PM for UAS in July 2015.[37] Note that the first challenge/concern listed is that S&T investment is needed for Group 3 and

[37] John Beck, "Army UAS Update," briefing to Huntsville Aerospace Marketing Association, 15 July 2015, http://hamaweb.org/presentations/2015/july2015johnbeck.pdf

above (such as Shadow and Gray Eagle) and that it is assumed that industry will drive the S&T for smaller platforms.

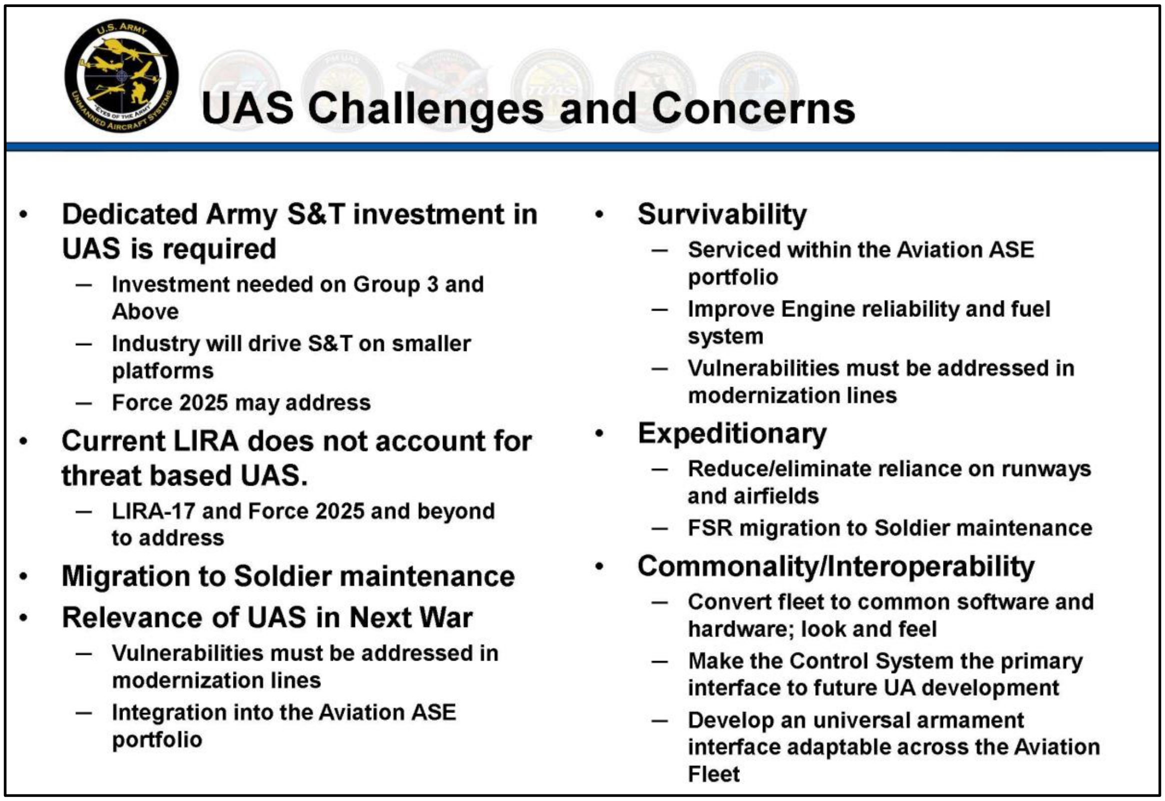
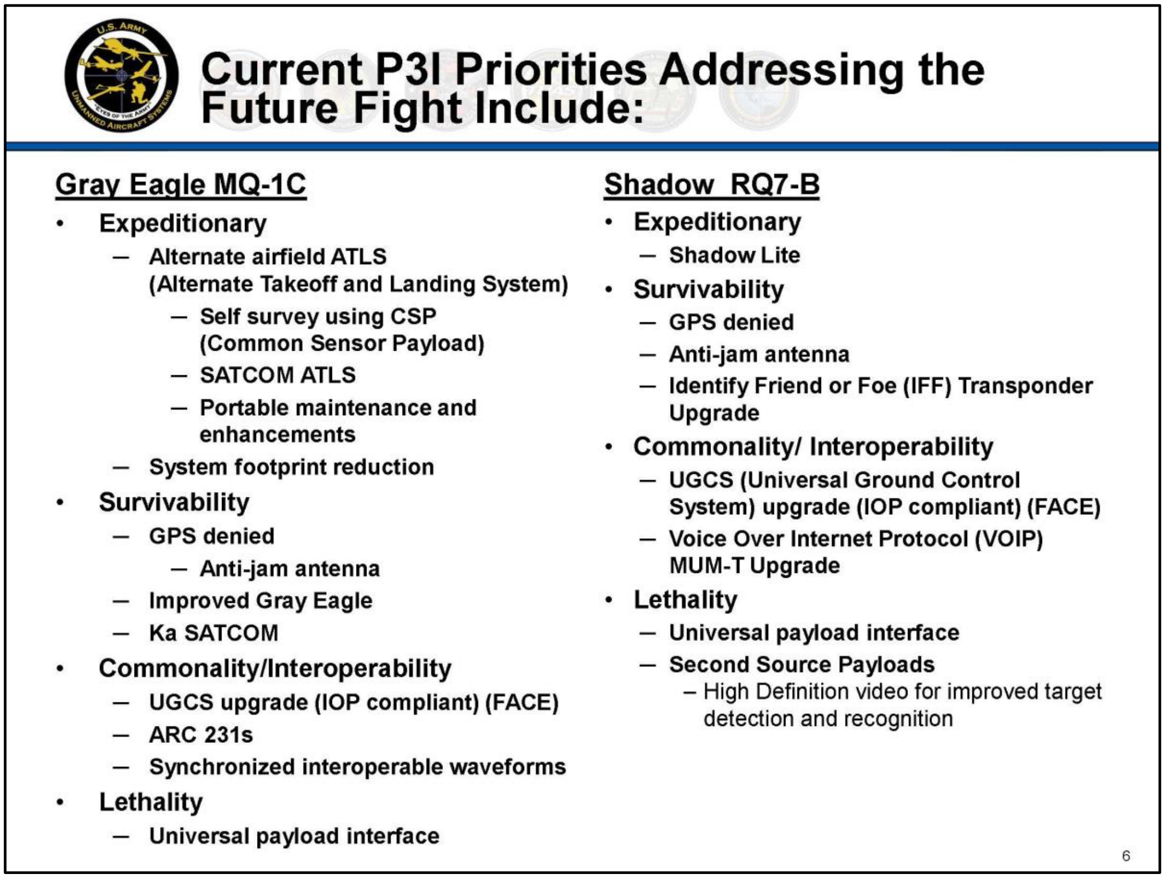


Figure E-4 UAS Challenges and Concerns

The Army P3I priorities to address these concerns for the larger UAS platforms are displayed in Figure E-5. Note that interoperability and commonality are cited for both platforms.

AMRDEC Aviation has been given the responsibility to develop UAS technology for both new systems and modernization of legacy systems, but they have generally not been given additional funds to do so. As a result, Army S&T has relied on industry to develop the UA vehicles. The tendency is for the development companies to build a package that includes both the vehicle and ground control system (GCS), inhibiting development of a common control system. For example, both Shadow and Gray Eagle have unique operating systems and mission packages. While the GCS for Shadow and Gray Eagle is called a Universal Ground Control System (UGCS), it is optimized for one or the other and cannot easily transition to a different vehicle. For example the Gray Eagle GCS has functions to control SATCOM and Link-16 communications, weapons and SAR payloads; the Shadow system does not. An additional complication is that the communications equipment is located in the GCS rather than in the vehicle.



ATLS - Alternate Takeoff and Landing System
CSP - Common Sensor Payload
UGCS - Universal Ground Control System
VOIP – Voice over Internet Protocol

Figure E-5 P3I Priorities for Larger Legacy UAS

The US Army Roadmap for Unmanned Aircraft Systems[38] is subtitled "Eyes of the Army" reflecting the Army's current focus on using UAS for ISR. It is anticipated that cargo/sustainment UAS will be introduced in the mid-term (2016-2025). Improved networking will permit improved information distribution in the same timeframe. By the far-term (2026-2035) technology advances will permit operators to control multiple UAS from a common control system.

These considerations led to the ASB recommendation that ASA(ALT) should revise the UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, …).

[38] US Army UAS Center of Excellence, "*Eyes of the Army," U.S. Army Unmanned Aircraft Systems Roadmap 2010-2035*, 2010, http://www-rucker.army.mil/usaace/uas/us%20army%20uas%20roadmap%202010%202035.pdf .

E.4 Basic Research

S&T is summarized by REDCOM as:[39]

- **Discovering, Maturing** and **Demonstrating** technologies that support the desired Army (in this case Army Aviation) capabilities and then **combining technologies** into **capabilities.**
- **There are three major types of S&T**
  - **6.1 Basic Research:** Fundamental Science, system non-specific
  - **6.2 Applied Research:** Component Level, Concept Development
  - **6.3 Advanced Technology Development:** System Level, Concept Field Demonstration
- **There are two major strategies**
  - Develop body of technical **knowledge** that supports decisions
  - Develop early versions of **"the system"**

S&T is **not** engineering work for existing platforms. Figure E-6 describes S&T in RDECOM; basic research is distributed between ARL/ARO and the RDECS (AMRDEC for Aviation).

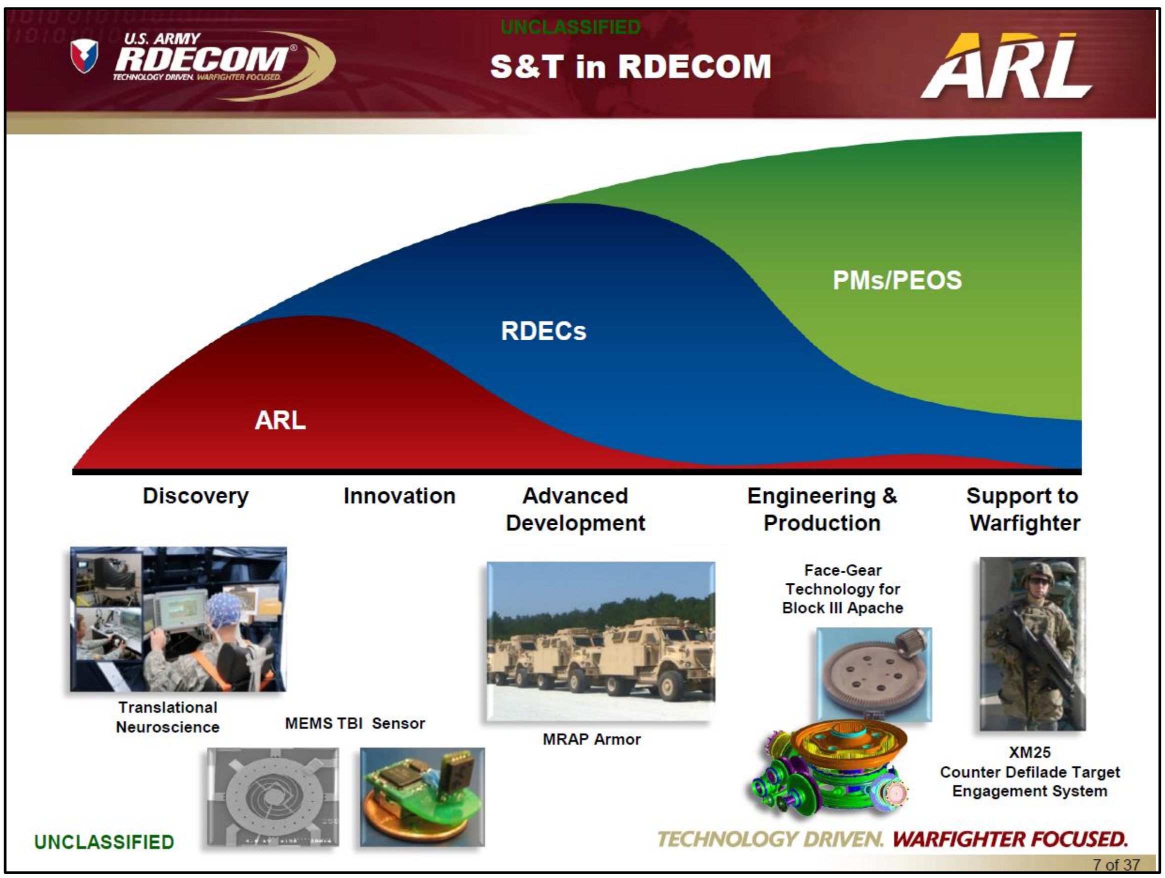


Figure E-6 S&T in RDECOM

[39] Army Aviation Technical Panel briefing to Army Aviation Home-on-Home, 22 January 2015.

Figure E-7 shows Aviation S&T and how 6.1 basic research fits within the overall portfolio. The 6.2/6.3 elements shown are discussed in their respective sections within the main body of this report and/or the appendices.

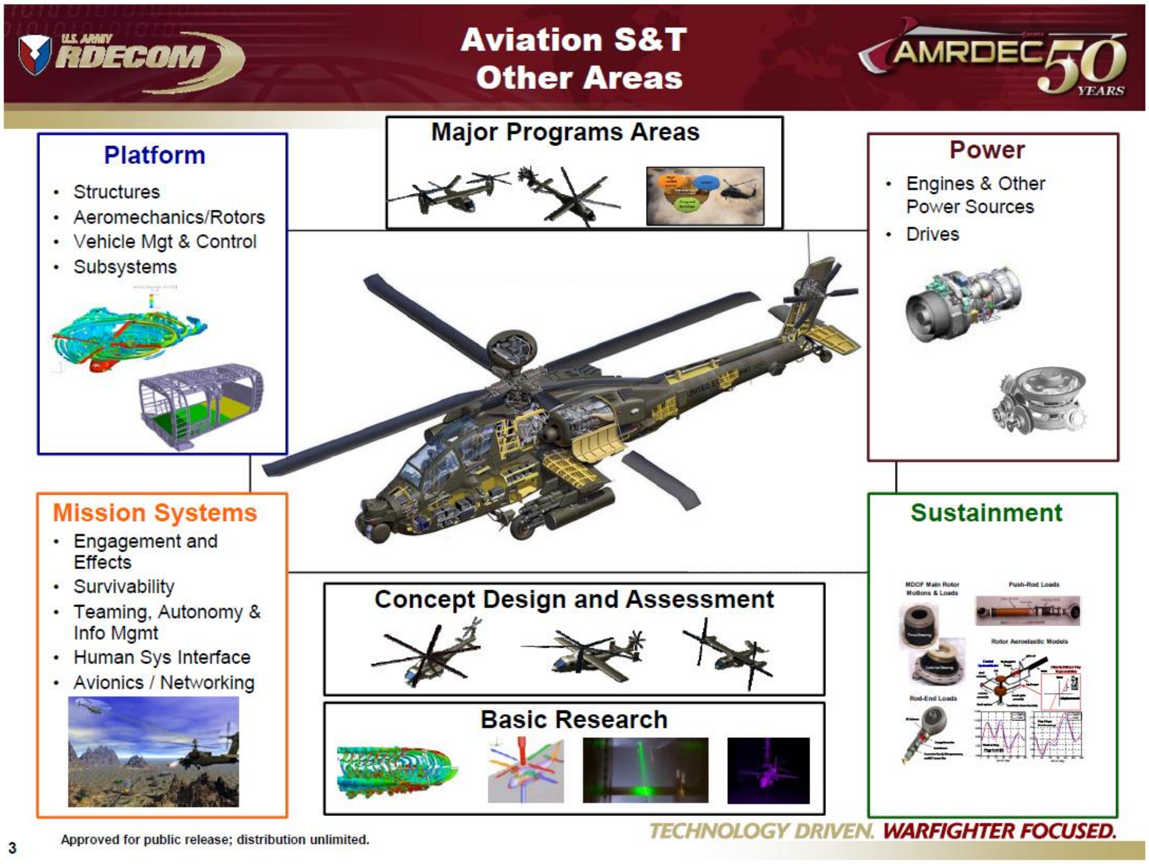


Figure E-7 Aviation S&T - 6.1 Basic Research Supports the Overall Portfolio

Figure E-8 presents an overview of the overall 6.1 Basic research portfolio supporting Army Aviation, distributed across ARL/ARO and AMRDEC including the University Centers of Excellence at Georgia Tech, University of Maryland and Penn State University that combine basic research with graduate education.

Figure E-9 shows a deeper dive into the Aeromechanics elements within the 6.1 basic research portfolio. Figure E-10 presents the aviation 6.1 basic research focus area road map that connects the 6.1 basic research to the 6.2 research areas out to FY 21.

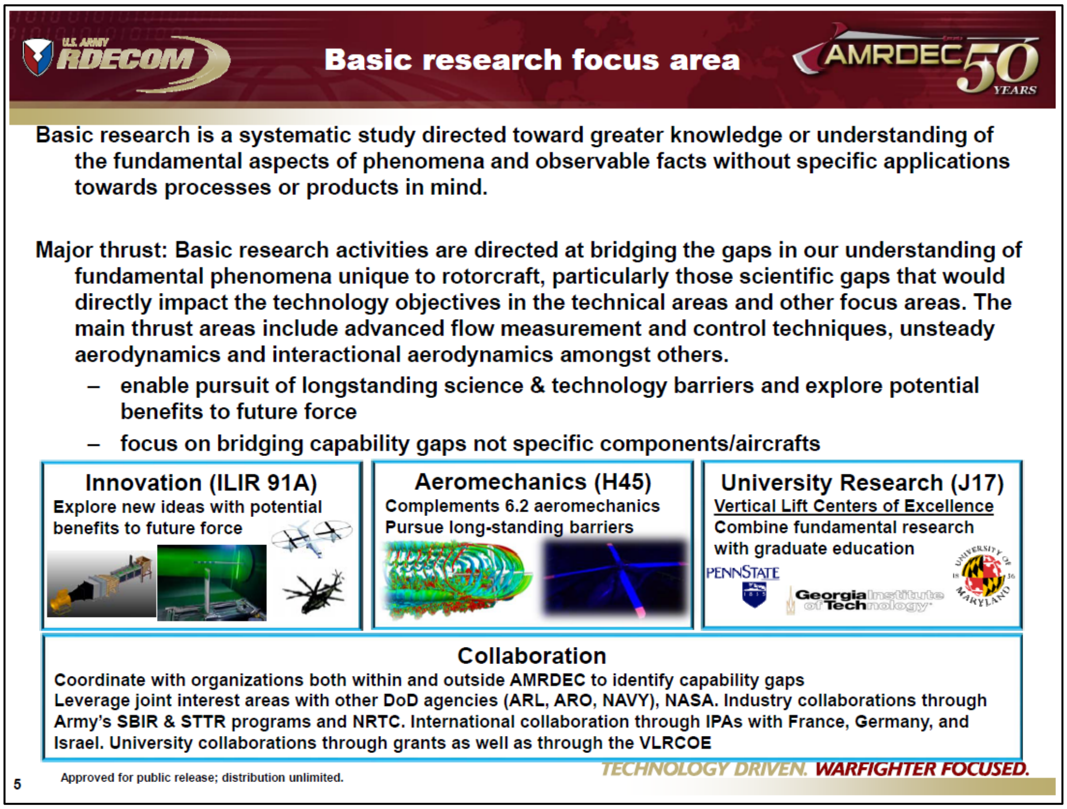


Figure E-8 Overview of the Basic Research portfolio to Support Army Aviation

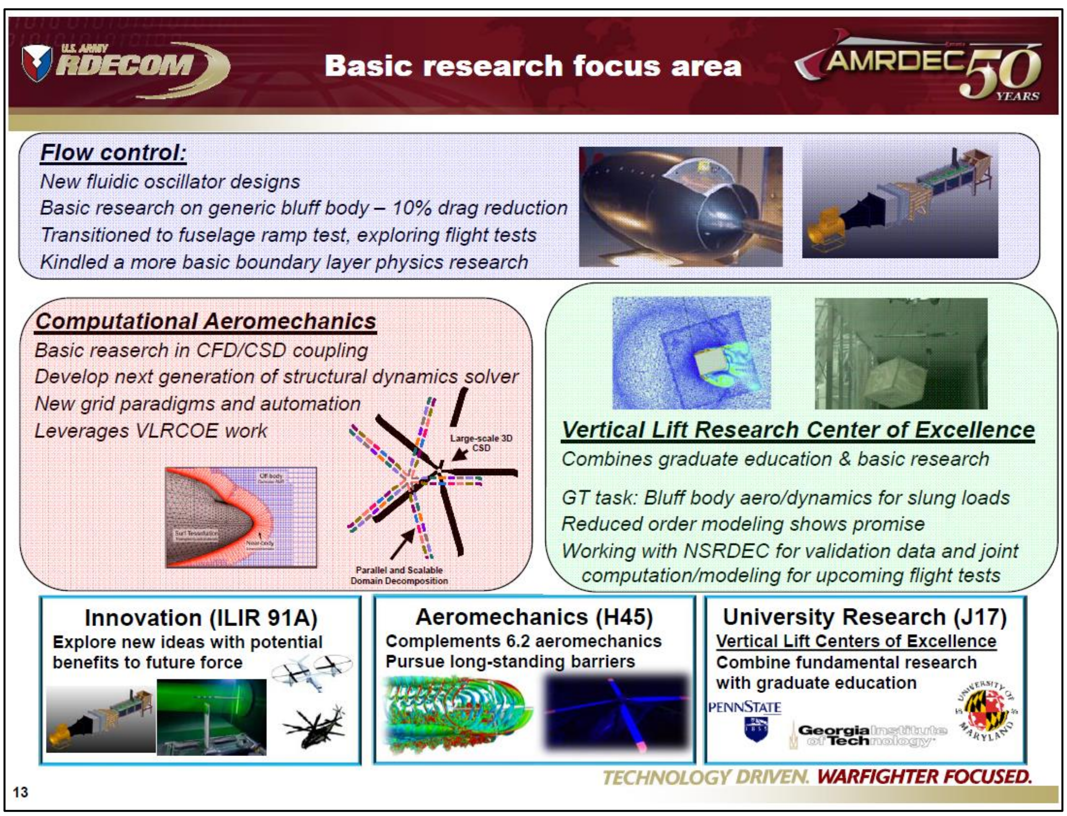


Figure E-9 A Deeper Dive into the Aeromechanical Elements Basic Research

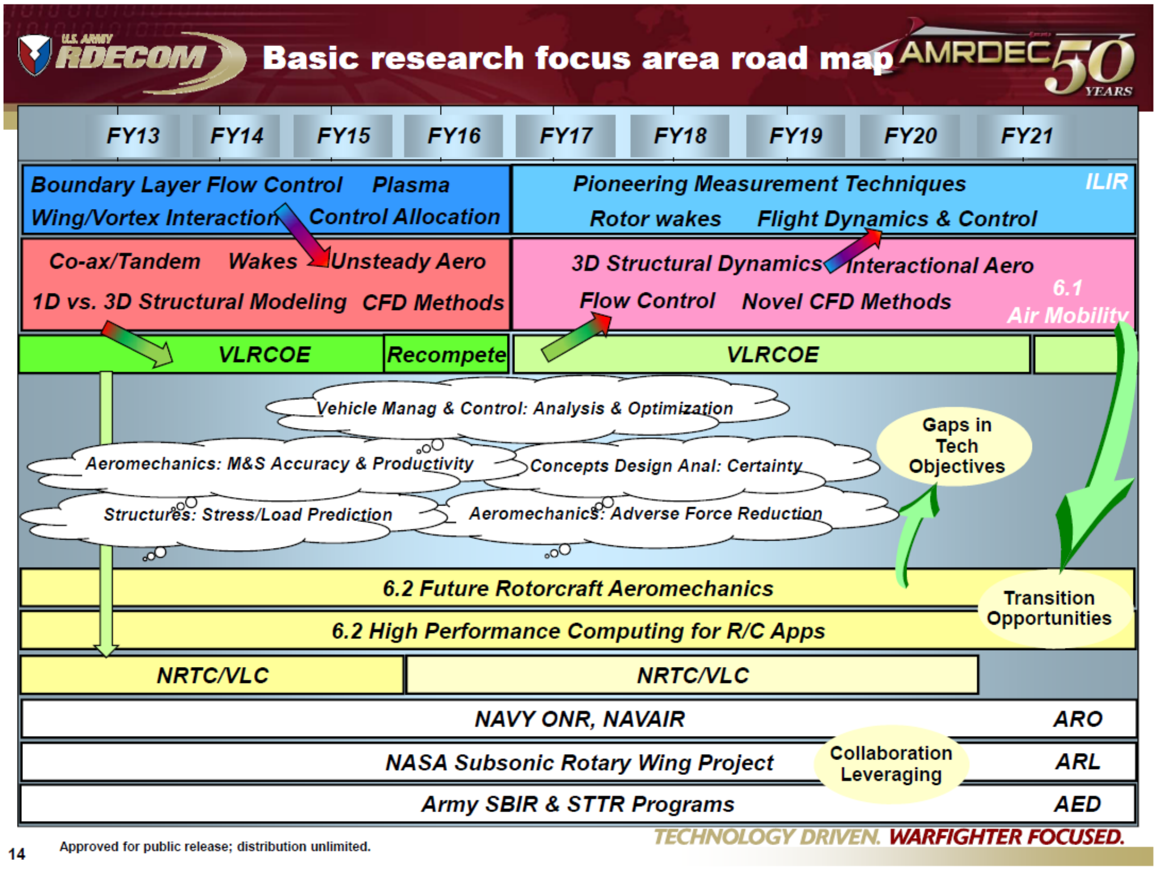


Figure E-10 Aviation Basic Research Focus Area Road Map

Finally, it is important to point out a new laboratory business model termed the "Open Campus Initiative" put forward by ARL. The concept for this ARL initiative is shown in Figure E-11. This innovative approach holds forth the promise of leading to breakthroughs by allowing university/industry researchers extensive access to ARL laboratory facilities and provides an opportunity to have ARL staff work closely with university researchers including faculty, Ph.D. students and post docs as well as industry researchers.

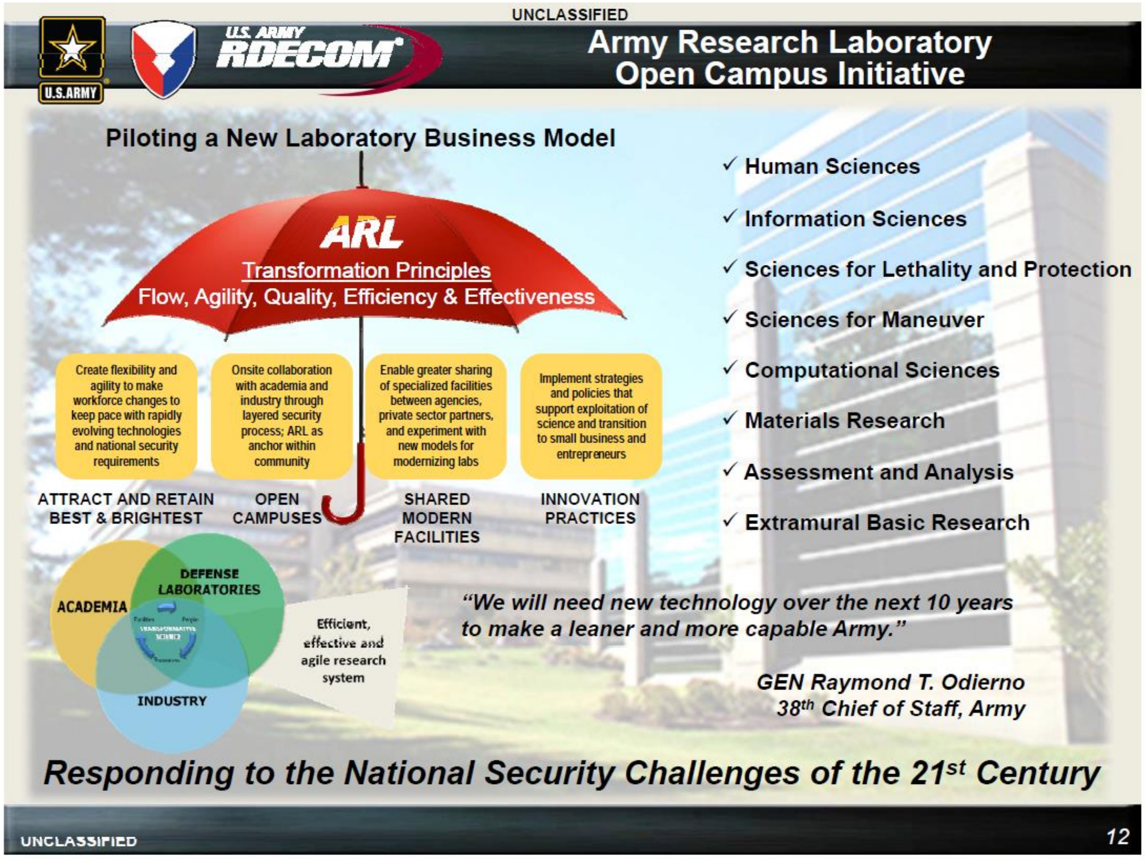


Figure E-11 The ARL Open Campus Initiative

APPENDIX F OTHER EFFORTS IN MANNED AND OPTIONALLY MANNED ROTORCRAFT

Task 1 of the TOR directs the study team to review current government and industry aviation plans and programs. Army systems are described in the main part of the report and in Appendix E. The remainder of this section describes the information obtained regarding other efforts on manned and optionally manned rotorcraft.

Figure F-1 summarizes the characteristics of current and near-term DoD rotorcraft with the heaviest platforms at the top. Note that the largest, the King Stallion CH-53K, will be able to lift 35,000 lb and is expected to reach IOC with the Marine Corps in 2018. It is also noteworthy that only two of the remaining rotorcraft, the Osprey and Lakota, have an IOC within the last 25 years.

The Osprey has a cruise speed of 241 kt, the only rotorcraft to exceed 200 kt; it is also the only tilt-rotor on the list.

The Army is funding the only developmental rotorcraft effort in the Services, the Joint Multi-Role Technology Demonstrator (JMR-TD). Two demonstrators are funded for flight tests in 2017. The Bell demonstrator is a tilt-rotor that builds on Osprey technology. The Boeing-Sikorsky demonstrator is a coaxial rigid-rotor, pusher-propulsor design. Both industry teams have invested significant internal resources in the effort. The JMR-TD is described in detail in APPENDIX D.

DARPA is funding the VTOL X-Plane program. Flight demonstrations will take place in 2017-2018. This effort is described in detail in Section F.4

Industry is also funding development efforts in proprietary programs. On 22 May 2015 Sikorsky announced the successful first flight of the S-97 Raider helicopter.[40]

[40]Sikorsky press release, "Sikorsky S-97 RAIDER™ Helicopter Achieves Successful First Flight," 22 May 2015, http://raider.sikorsky.com/raider-first-flight.asp.

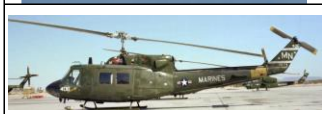
DoD Current and Near-Term Rotorcraft	Name / Designator	Role	IOC	Service	Max Takeoff (lb)	Max Load	Cruise Speed/ Range	Developer (inventory)
	King Stallion CH-53K	Cargo	2018	USMC	84,700	35,000 lb	170 kt / 460 nm	Sikorsky
	Super Stallion CH-53E & Sea Dragon MH-53	Cargo Multi-mission	1981	USMC & USN	73,500	30,000 lb int, 32,000 lb ext	150 kt / 540 nm	Sikorsky (176)
	Osprey C/MV-22	Cargo, Multi-mission	2006	USAF & USMC	52,870	10,000 lb	241 kt / 1,000 nm	Bell (231)
	Chinook CH-47D/F	Cargo	1962	USA	50,000	28,000 lb	130 kt / 400 nm	Boeing (503)
	Whitehawk VH-60N	VIP Trans-port	1988	USMC	23,501		159 kt max / 1200 nm	Sikorsky (8)
	Black Hawk UH-60	Utility	1979	USA	23,500	2,640 lb int, 9,000 lb ext	159 kt / 640 nm	Sikorsky (1,565)
	Pave Hawk/ Rescue Hawk HH-60	Search & Rescue	1981	USAF & USN	22,000	5,000 lb	159 kt / 324 nm	Sikorsky (149)
	Seahawk, M/SH-60	ASW, multi-mission	1984	USN	21,884	6,684 lb	146 kt max / 450 nm	Sikorsky (460)
	Apache AH-64	Attack	1986	USA	23,000		143 kt / 257 nm	Boeing (756)
	Sea King VH-3D	VIP Trans-port	1976	USMC	22,050		144 kt max / 540 nm	Sikorsky (11)
	Super Cobra, AH-1W & Viper AH-1Z	Attack	1986	USMC	14,750		190 kt max / 317 nm	Bell (161)
	Twin Huey, UH-1N & Venom, UH-1Y	Utility	1970	USAF & USMC	10,500	4,500 lb	110 kt / 248 nm	Bell (154)
	Lakota UH-72	Trainer, CONUS only	2007	USA	7,900	3,950 lb	133 kt / 370 nm	Eurocopter (307)
	Kiowa OH-58D	Observa-tion	1969	USA	5,500	1,700 lb	110 kt / 140 nm	Bell (618)
	Little Bird A/MH-6	SOF	1980	USA	3,100	1,500 lb (6 pax)	135 kt / 232 nm	McDonnell Douglas / Boeing (47)

Figure F-1 DoD Current and Near-Term Rotorcraft

F.1 OSD Air Platforms Community of Interest

The Office of Secretary of Defense (OSD) has established 17 Communities of Interest (COIs) to encourage multi-agency coordination and collaboration:

1) Advanced Electronics
2) Air Platforms
3) Autonomy
4) Biomedical
5) CounterIED
6) CounterWMD
7) Cyber Security
8) Electronic Warfare
9) Energy & Power Technologies
10) Engineered Resilient Systems
11) Ground & Sea Platforms
12) Human Systems
13) Command, Control, Comms, Computers, and Intelligence (C4I)
14) Materials & Manufacturing Processes
15) Sensors
16) Space
17) Weapons Technologies

The Air Platforms COI is led by the Air Force. The Army principal is Bill Lewis of AMRDEC.

COIs develop technology roadmaps for the relevant technology areas and describe the cross-organization interactions in terms of four levels of coordination:

1) Information Sharing
2) Active Coordination (deconflicted, not joint)
3) Building Joint S&T Roadmaps
4) Delivering Joint S&T Roadmaps

The Air Platforms COI is primarily Level 2 (for technologies that are predominantly single-Service investment) and Level 3 (for technologies of common interest).

Air Platform Technology Sub-Areas are 1) Fixed Wing Vehicles, 2) Rotary Wing Vehicles, 3) High Speed/Hypersonics, and 4) Aircraft Propulsion, Power and Thermal. In the funding request for FY16 $207M is planned for S&T in rotary wing vehicles. The Army provides over 60% of the proposed S&T funding for rotary wing vehicles; DARPA plans to provide over 20% and the Navy/Marine Corps will provide over 10%. OSD plans to provide a small amount for rotary wing S&T (on the order of $350K). Specific OSD projects were not identified.

F.2 Navy/Marine

The USN and USMC operate a number of manned vertical lift platforms for a variety of missions. Among these are the AH-1, UH-1, VH-3, HH-60, M/SH-60, C/MV-22 and CH-53. Of most interest to potential Army aviation applications are the V-22 and CH-53K.

The V-22 Osprey Tilt-Rotor, with a speed of approximately 250 knots, is the only deployed vertical lift platform within the DoD inventory with a speed that can satisfy the FVL requirement. In fact, the V-22 tilt-rotor technology provides the basis for one of the JMR-TD vehicles, which will demonstrate FVL aerodynamic capabilities, including speed. While V-22 does not satisfy other FVL requirements, it could serve as a back-up interim capability for the most speed-critical FVL missions (e.g., MEDEVAC) in the event of unanticipated programmatic delays to the FVL program. In addition, some of the V-22 technology efforts could be of benefit to Army aviation rotorcraft systems. These include material efforts, such as rotorcraft blade coatings, engine blade wear coatings and windscreen coatings. Relevant aerodynamic technology efforts include active flow control and external carry at high speeds. AMRDEC is tracking these S&T efforts to exploit advances relevant to Army aviation.

The Army CH-47F currently has the greatest vertical lift load capacity of Army deployed platforms, rated at 14 stons. However, at hot/high conditions, the external load is 6 stons at 20 nm. As is shown in Figure F-2, this load capacity can be greatly improved to 9 stons at 20 nm with a future upgrade to the Future Affordable Turbine Engine (FATE).

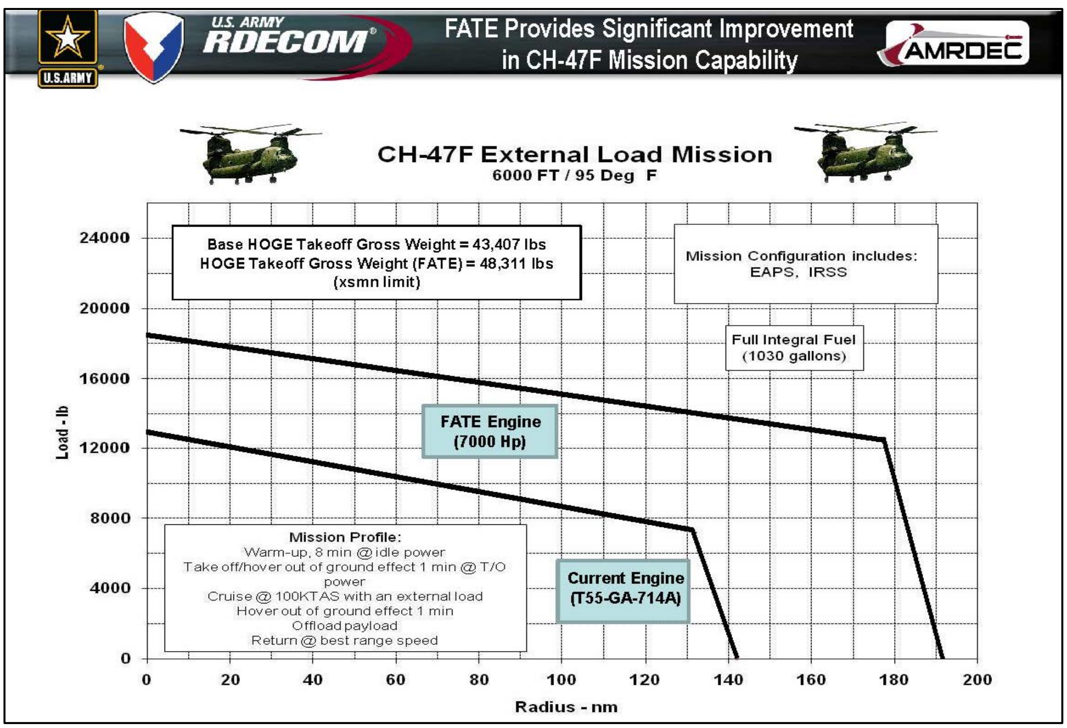
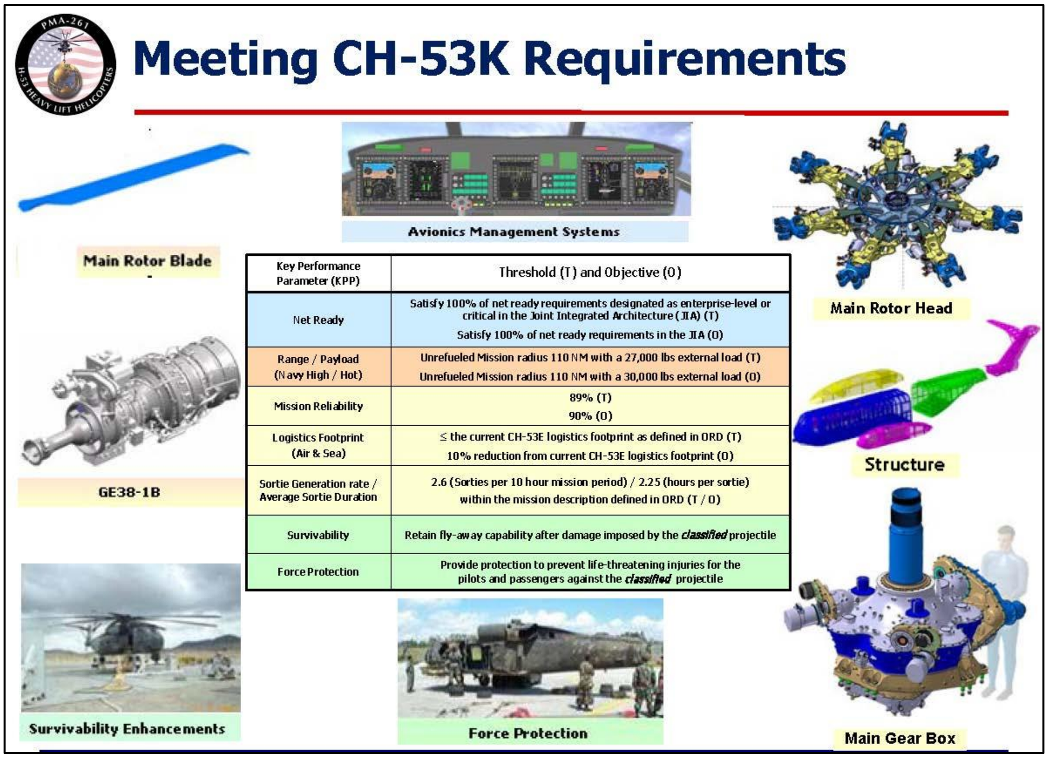


Figure F-2 Future Affordable Turbine Engine Improvement for CH-47

The latest version of the USN CH-53, the CH-53K, has an external load capacity of 18 stons. The requirement is for an external load capability of 15 stons at 110 nm (Figure F-3). While 18 stons is still shy of the Joint Heavy Lift (JHL) requirement of 20-30 stons, the CH-53K could provide the Army with a significant increase in heavy vertical lift capability if it becomes evident that a JHL program is unaffordable anytime in the foreseeable future. From an S&T perspective, the Army should benefit from technologies being developed for CH-53K (Figure F-4).



Key Performance Parameter (KPP)	Threshold (T) and Objective (O)
Net Ready	Satisfy 100% of net ready requirements designated as enterprise-level or critical in the Joint Integrated Architecture (JIA) (T) Satisfy 100% of net ready requirements in the JIA (O)
Range / Payload (Navy High / Hot)	Unrefueled Mission radius 110 NM with a 27,000 lbs external load (T) Unrefueled Mission radius 110 NM with a 30,000 lbs external load (O)
Mission Reliability	89% (T) 90% (O)
Logistics Footprint (Air & Sea)	≤ the current CH-53E logistics footprint as defined in ORD (T) 10% reduction from current CH-53E logistics footprint (O)
Sortie Generation rate / Average Sortie Duration	2.6 (Sorties per 10 hour mission period) / 2.25 (hours per sortie) within the mission description defined in ORD (T / O)
Survivability	Retain fly-away capability after damage imposed by the *classified* projectile
Force Protection	Provide protection to prevent life-threatening injuries for the pilots and passengers against the *classified* projectile

Figure F-3 CH-53 Requirements

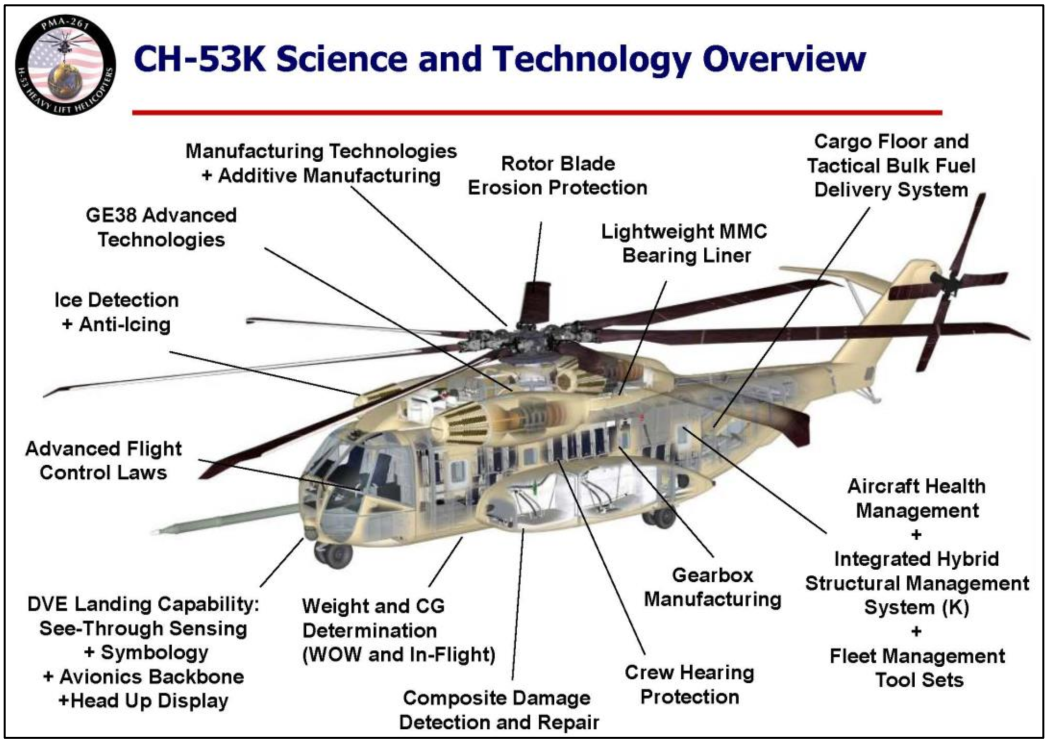


Figure F-4 CH-53K Science and Technology

F.3 Air Force

Beginning with the Key West Agreement[41] in 1948, there have been numerous documents that define the separate responsibilities of the Army and Air Force with respect to air transport. The Air Force has responsibility for longer-range transport and has chosen to use fixed wing aircraft for the purpose.

An Air Force presentation to the House Armed Services Committee on Air Force Rotorcraft Programs[42] stated:

> Air Force rotary wing assets are critical to the mission of the Air Force and provide worldwide support to Combatant Commanders. The HH-60G supports the Service's Core Function of Personnel Recovery. Additionally, the UH-1N provides security for Nuclear Operations while also ensuring continuity of government and continuity of operations in the National Capital Region. Another H-1 variant, the TH-1H, provides a modern platform for the rotary wing track of

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[41] Richard Wolf, *The United States Air Force: Basic Documents on Roles and Missions*, 1987, http://www.afhso.af.mil/shared/media/document/AFD-100525-080.pdf

[42] Kane, Major General Robert and Major General Noel Jones, *Presentation to the House Armed Services Committee, Subcommittee on Tactical Air and Land Forces – Air Force Rotorcraft Programs*, 27 March 2012, http://armedservices.house.gov/index.cfm/files/serve?File_id=d305f5a9-ce63-4b12-b815-3a459128ea9e

> Air Force undergraduate pilot training. Finally, the CV-22 provides US Special Operations Command with a unique long-range vertical lift capability.
>
> . . .
>
> The Air Force continues to participate in the DoD-wide Future Vertical Lift effort to ensure a joint roadmap informs future modernization efforts. While fiscal constraints may have required us to reassess the timing of some rotary wing modernization efforts, the Air Force's commitment to rotary wing modernization remains strong.

Thus there are several niche roles for rotary wing aircraft in the Air Force. In general the Air Force adapts aircraft developed by another Service.

F.4 DARPA

DARPA is currently funding the Vertical Takeoff and Landing (VTOL) Experimental Aircraft (X-Plane) effort. This $130 million project will cover 52 months, from 2013 to 2018, in three phases:

- Phase 1: develop a preliminary concept design for aircraft (4 primes)
- Phase 2: develop, construct, and integrate (1 prime)
- Phase 3: conducting flight test demonstrations by 2017-2018 (1 prime)

Conventional rotorcraft are limited to about 175 knots. Fixed wing aircraft achieve higher speeds but are not as agile as a helicopter. The DARPA effort has four specific goals:[43]

- Speed: Achieve a top sustained flight speed of 300 kt-400 kt
- Hover efficiency: Raise hover efficiency from 60 percent to at least 75 percent
- Cruise efficiency: Present a more favorable cruise lift-to-drag ratio of at least 10, up from 5-6
- Useful load capacity: Maintain the ability to perform useful work by carrying a useful load of at least 40% of the vehicle's projected gross weight of 10,000-12,000 pounds

The effort focuses on unmanned aircraft but technology developed is applicable to manned aircraft as well.

The four competing designs in Phase 1 are shown in Figure F-5: [44]

- Boeing Phantom Swift – Four ducted fans - 2 body lift fans fore and aft and 2 wingtip thrusters that tilt for forward flight
- Karem – tilt rotor with optimum speed rotor
- Sikorsky (w/ Lockheed Skunk Works) – tail-sitter aircraft using rotor blown wing

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[43] Dr. Ashish Bagai, "Vertical Takeoff and Landing Experimental Plane (VTOL X-Plane)," http://www.darpa.mil/program/vertical-takeoff-and-landing-experimental-plane accessed 27 Oct 2015.

[44] Richard Whittle, "The Next X-Plane," *Air and Space Magazine*, October 2015.

- Aurora Flight Sciences Lightning Strike – electric generators that drive 24 fans that tilt upward for lift and forward for horizontal flight, 18 are in a wing near the tail of the aircraft and 6 are on a canard near the nose

Downselect from four contractors to one is expected late 2015/early 2016.

Figure F-5 DARPA VTOL X-Plane Designs

F.5 Army Special Operations

In addition to Chinook and BlackHawk, Army Special Operations uses the AH-6/MH-6 Little Bird attack/utility helicopter shown in Figure F-6. Little Bird is used for close air support of ground troops, target destruction raids, and armed escort of other aircraft. It is a small (3,100 lb max takeoff) aircraft that is less detectable than the larger platforms.

Figure F-6 Little Bird carrying Rangers strapped to benches along the fuselage.

F.6 NASA

The Revolutionary Vertical Lift Technology Project (RVLT) is part of the overall NASA Advanced Air Vechicles (AAV) which is shown in Figure F-7. Other projects within the AAV Program, including the Advanced Air Transport Project, the Advanced Composites Project and the Aeronautical Evaluation & Test Capabilities Project, provide some peripheral basic support for the RVLT project.

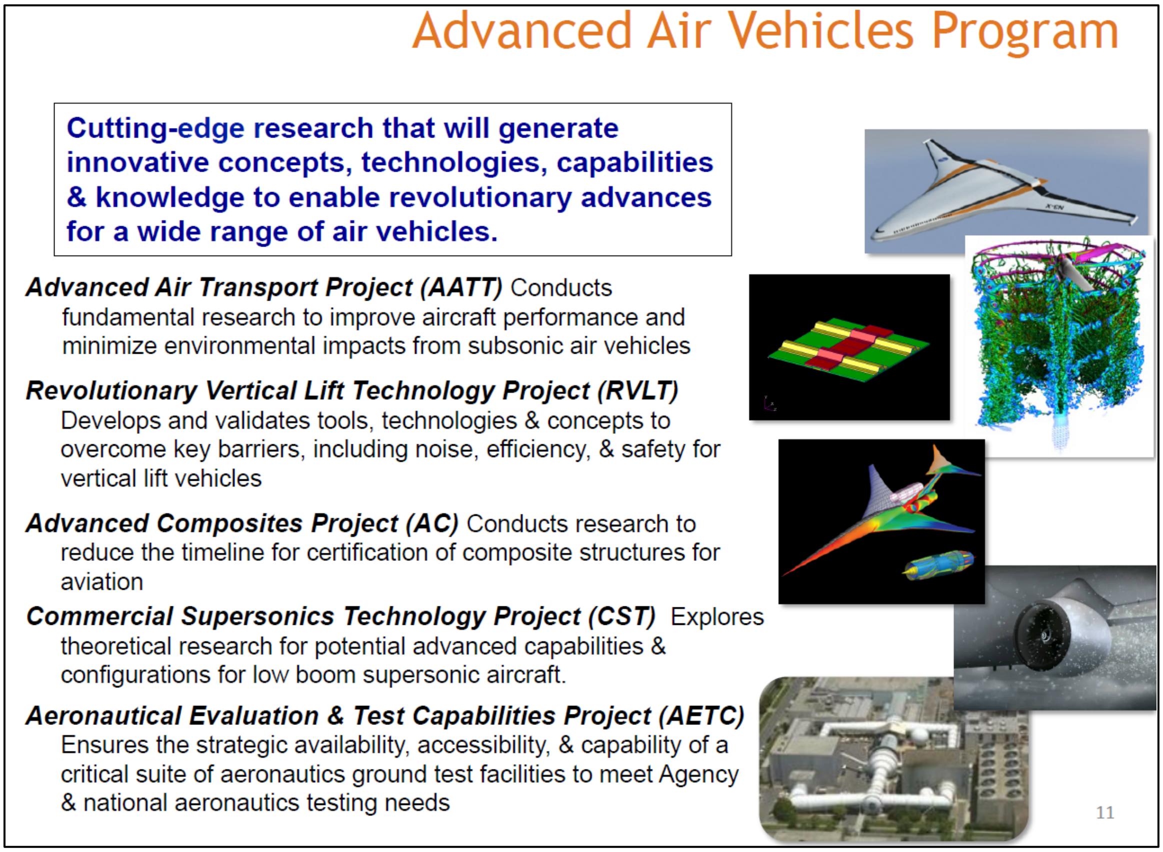


Figure F-7 NASA Advanced Air Vehicles Program

Figure F-8 shows the future capabilities that the RVLT project contains which supports the development and validation of tools, technologies and concepts to overcome key barriers for Vertical Lift Vehicles. These key challenges are shown in Figure F-9

The vision of the RVLT project is to enable the development of vertical lift vehicles with aggressive goals for efficiency, noise, and emissions to expand current capabilities and develop new commercial markets. The scope of the RVLT project is two-fold:[45]

1. Development of conventional and non-conventional very light, light, medium, heavy and ultra-heavy vertical lift configurations.
2. Development of technologies that address noise, performance, efficiency, safety, community acceptance and affordability. These include:
   a. Advanced Efficient Multi-speed Propulsion: Demonstrate and mature propulsion and drive system technologies to enable increased vehicle speeds while maximizing propulsive efficiency and minimizing weight penalty. Figure F-10 shows the development schedule through FY20 for this technology.

[45] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: 1) Jay Dyer, "ARMD and Advanced Air Vehicles Program Overview" and Susan A. Gorton, "Revolutionary Vertical Lift Technology Project Overview"

b. Low-Noise Vertical-Lift Concepts and Configurations: Demonstrate and mature aeromechanics technologies to enable design, analysis, testing, and optimization of low-noise vertical lift concepts. Figure F-10 shows the development schedule through FY20 for these technologies.

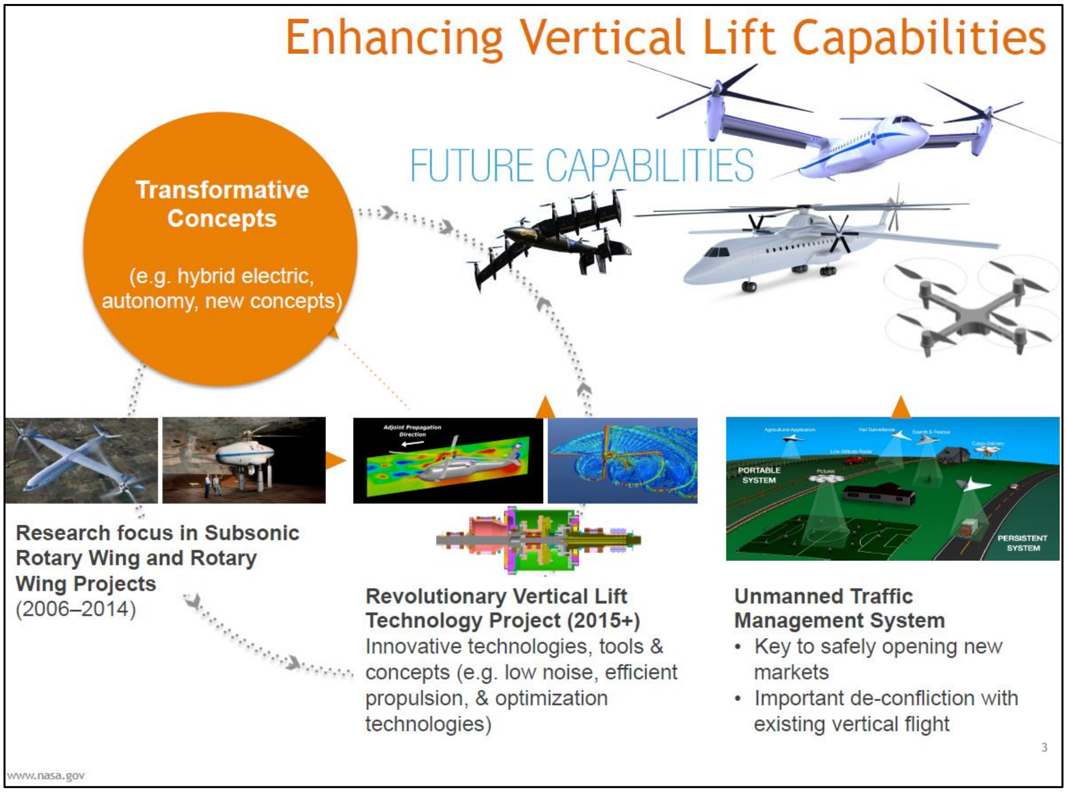


Figure F-8 Future Vertical Lift Capabilities supported by the NASA RVLT Program

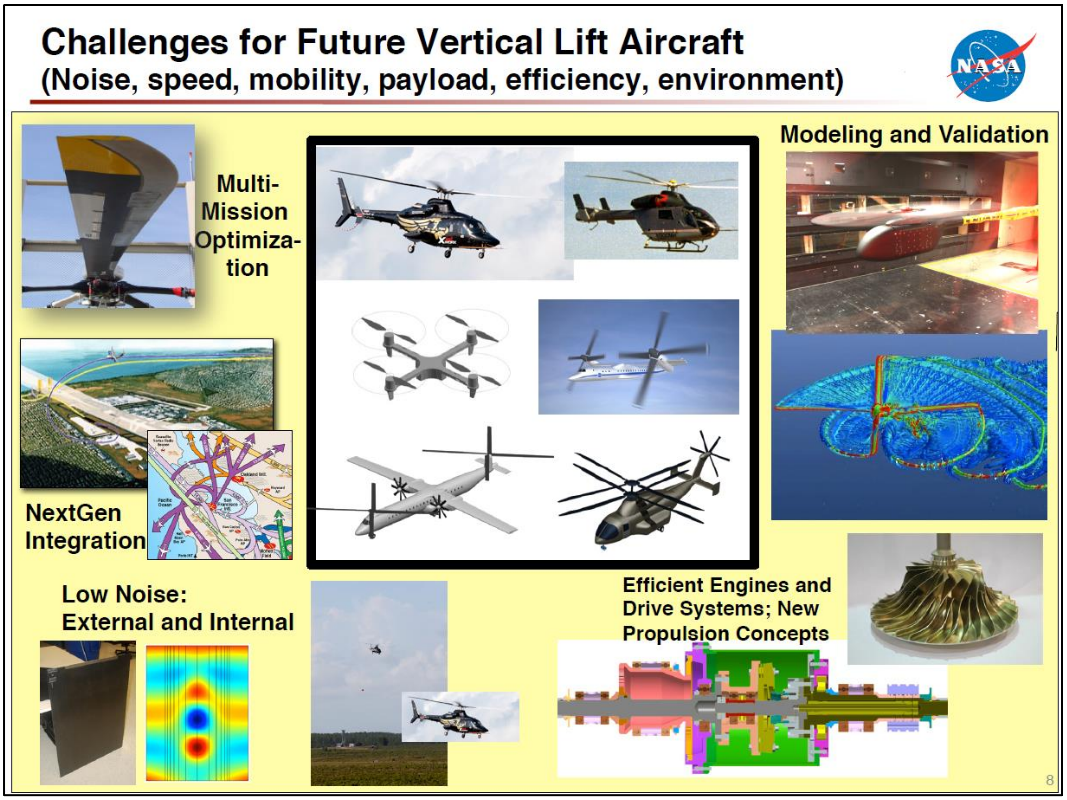


Figure F-9 Challenges for the future vertical lift aircraft

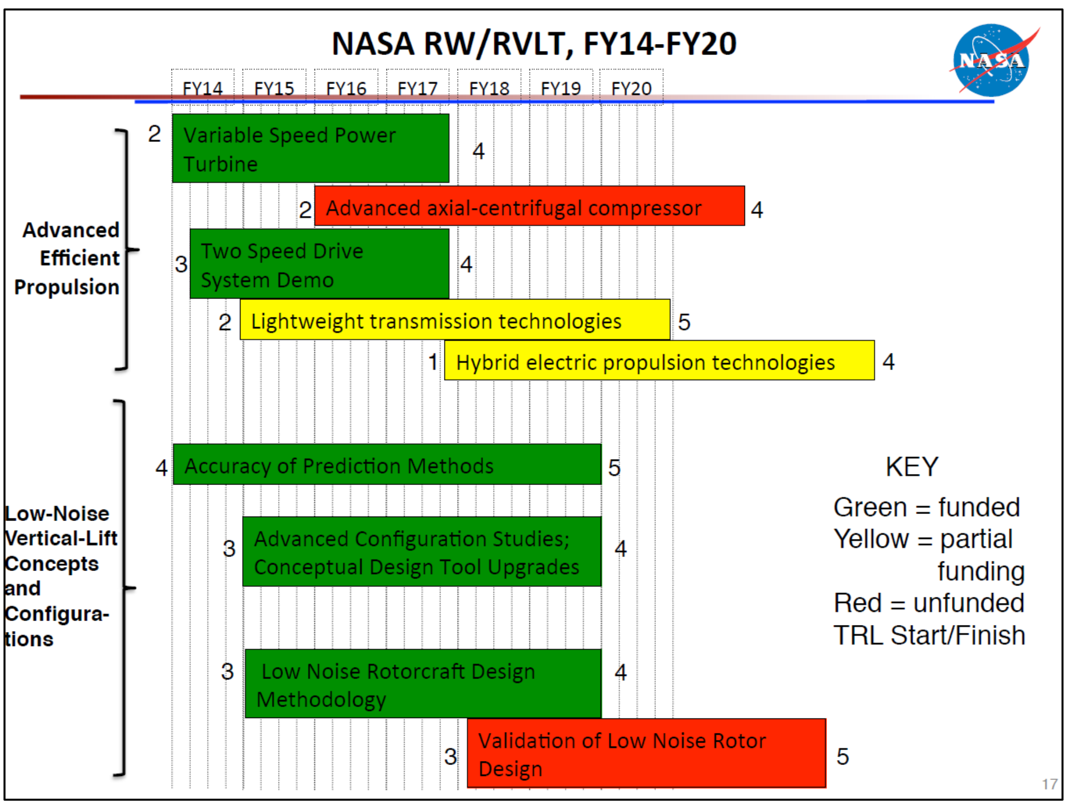


Figure F-10 Schedule for Development of RVLT technologies through FY20

Figure F-11 provides an overview of the interaction between NASA and DoD. This has been a very effective relationship that has been ongoing for 50 years. The challenge for rotorcraft R&D is that NASA's funding levels are ~$20M per year (includes salary for ~65 Civil Service Workers) and similar levels of funding are anticipated for FY16-20. This relatively limited investment by NASA is already highly leveraged by the Army and supports the ASB Study Teams Recommendation 9, <u>advocate more funding</u> for Aviation S&T.

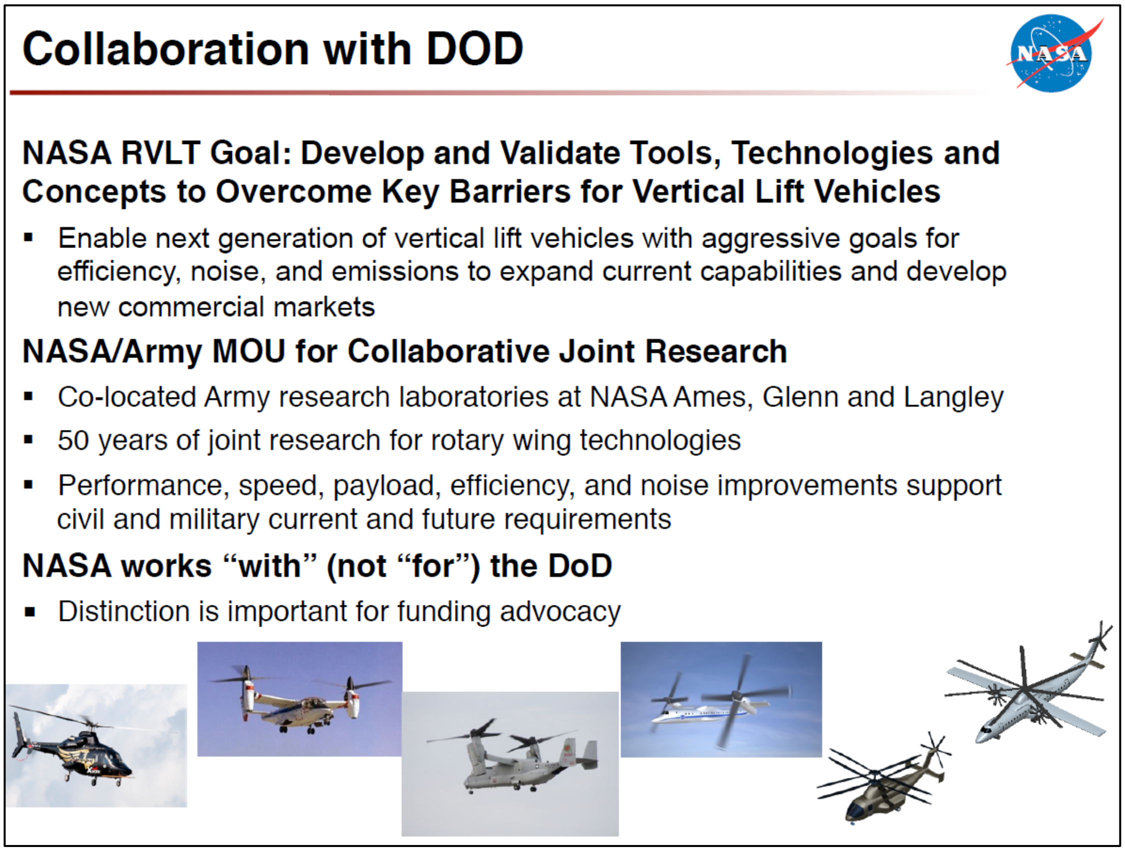


Figure F-11 Overview of the Interaction between NASA and DoD

F.7 Industry

Industry teams support Army aviation in the modernization of legacy rotorcraft systems and the development of new systems. For legacy systems, Sikorsky and its contractor team works closely with PEO-Aviation, AMRDEC and CERDEC in development of the UH-60 modernization roadmap and performs the development and production of upgrades under contract to PM UH-60. Likewise, the Boeing Company and its contractor team actively support the Army in modernization of AH-64 and CH-47. In both cases, the contractors work closely with RDECOM laboratories to develop technologies for insertion into the platforms. They also often invest company funds into technologies that may enable improved operational effectiveness or reduced operations and support costs for future upgrades of the systems.

Industry also invests in the development of new aviation systems and capabilities that may lead to future Programs of Record (PORs). A perfect example is the JMR-TD, in which the industry teams are more than matching Army S&T investment. Likewise, several industry teams are investing in the DARPA X-plane program and in USN/USMC rotorcraft developments.

Rotorcraft prototyping programs are particularly important to the health of the US military rotorcraft industry because new PORs are too infrequent to maintain design and development skills. The decline of US market share in the commercial helicopter market provides evidence that US leadership in rotorcraft system design and development is eroding. As indicated in Figure F-12, the total share of US industry ***combined*** is only 25%, while the two European companies, Airbus Helicopters and Augusta Westland have almost 60% of the world market.

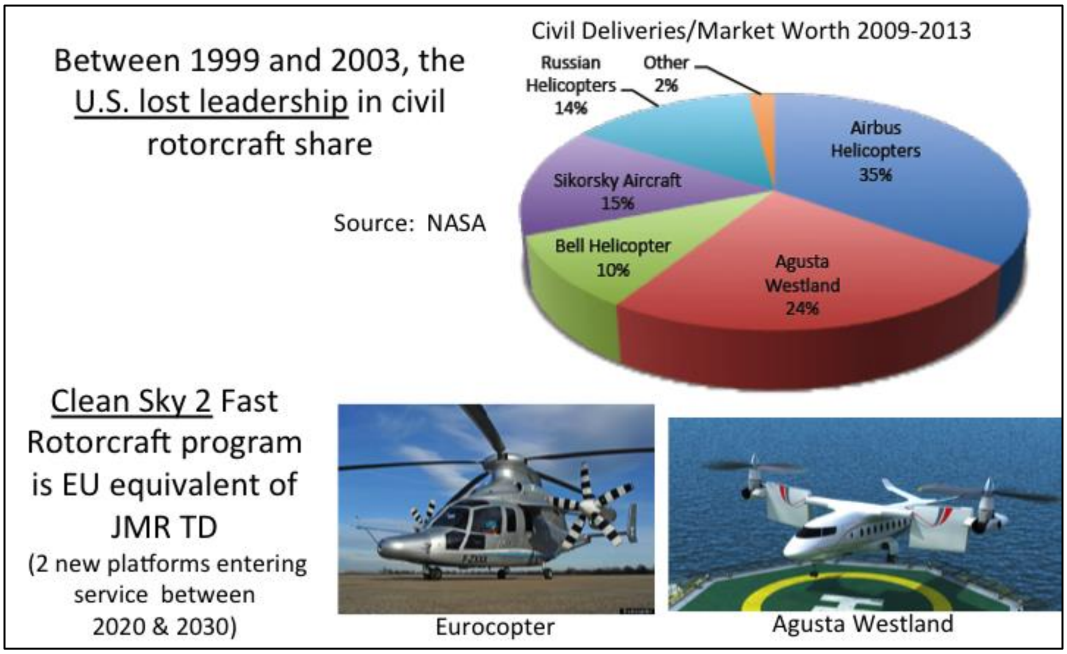


Figure F-12 Worldwide Competition

Concern regarding the health of the US rotorcraft industry has been voiced by the Vertical Lift Consortium (VLC). The VLC was established in 2009 in response to a memorandum from the Under Secretary of Defense AT&L that stated that the Future Vertical Lift initiative "will only be successful with the full support of, and partnership with, the vertical lift aircraft industry". The mission of the VLC is to "work collaboratively with the US Government to develop and transition innovative vertical lift technologies to rapidly and affordably meet warfighter needs." Its mission is to be a "cohesive national resource which various Government customers can efficiently access for innovative technologies to fulfill critical DoD vertical lift needs, which invigorates the US industrial base, drives innovation, and achieves an international competitive edge."

In its response to the FVL Executive Steering Group (ESG), the VLC indicated that the US has enjoyed global asymmetrical advantage from innovative technology that has been generated by a diverse, competitive research and industrial base and motivated by an engaged Government customer. However, continued advantage is not assured and Asia and Europe are at par and advancing.

Among the programs being sponsored by the European Union is the Clean Sky 2 Fast Rotorcraft Program, which has performance attributes similar to FVL and which is building two prototypes very similar to JMR-TD. A robust US rotorcraft industry is essential for the future of Army aviation, but that is certainly not assured in this global environment.

APPENDIX G ONGOING AND PLANNED DEVELOPMENT FOR UAS (INLCUDING MUM-T)

Task 1 of the TOR directs the study team to review current government and industry aviation plans and programs. Army Unmanned Aircraft Systems (UAS) are described in APPENDIX E. The remainder of this section describes the information obtained regarding other unmanned aircraft systems, both fixed wing and rotary wing as well as efforts in manned-unmanned teaming (MUM-T).

Figure G-1 provides definitions of the grouping used to describe DoD UAS, primarily based on size. Group 1 systems are handheld, operate at low altitude, and used by small units; Group 5 systems are high altitude platforms.

	Group 1	**Group 2**	**Group 3**	**Group 4**	**Group 5**
Size	Small	Medium	Large	Larger	Largest
Max Gross Takeoff Wt (lbs)	0-20	21-55	<1,320	>1,320	>1,320
Normal Operating Altitude (ft)*	<1,200 AGL	<3,500 AGL	<18,000 MSL	<18,000 MSL	>18,000
Airspeed (kts)	<100	<250	<250	Any	Any

* AGL – Above Ground Level, MSL – Mean Sea Level

Figure G-1 Grouping of DoD Unmanned Aircraft Systems (UAS)

Figure G-2 and Figure G-3 describe the current and near-term DoD UAS in Groups 1 through 5. Figure G-4 describes developmental systems.

DoD Current and Near-term UAS - Grp 1	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Wasp III	USAF & USMC	2007	ISR	3 lb	20 kt / 45 min	Aero-Vironment
	Raven RQ-11A/B	USMC, SOCOM & USA	1999	ISR	4 lb	30 kt / 1-1.5 hrs	Aero-Vironment
	Switchblade	USMC & USA	2012	Warhead	5.5 lb (inc. launcher)	55-85 kt / 10 min	Aero-Vironment
	Puma RQ-20A	USMC, USAF & USA	2007	ISR	13.5 lb	45 kt max / 2 hrs	Aero-Vironment

Figure G-2 DoD Current and Near-term UAS – Group 1

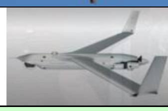
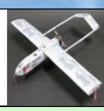
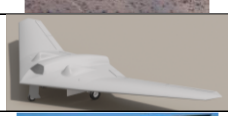
DoD Current and Near-term UAS - Grp 2	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Stalker	SOCOM	2006	5.5 lb	22.5 lb	43 kt max / 13 hr	Lockheed Martin
	ScanEagle	USN & USMC	2005	ISR	48.5 lb	60 kt / 24+ hrs	Boeing Insitu
DoD Current and Near-term UAS - Grp 3	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Blackjack RQ-21	USN	2014	ISR	135 lb	55 kt / 24 hrs	Boeing Insitu
	Shadow RQ-7	USMC & USA	2002	ISR	375 lb	70 kt / 9 hrs	AAI Corp (500)
DoD Current and Near-term UAS - Grp 4	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Snowgoose CQ-10B	SOCOM	2005	500 lb Cargo	1,400 lb	65 kt / 320 nm range	Mist Mobility Int Sys Tech (15)
	Predator MQ-1B	USAF	1995	ISR Pod / Hellfire	2,250 lb	70-90 kt / 24 hrs	General Atomics (154)
	Fire Scout MQ-8	USN	2009	ISR + weapons	3,150 lb	110 kt / 8 hrs	Northrup Grumman (27)
	Gray Eagle MQ-1C	USA	2009	ISR Pod / Hellfire	3,600 lb	150 kt max/ 30 hrs	General Atomics (75)
	Improved Gray Eagle	Gray Eagle Upgrade	2017	ISR Pod / Hellfire	4,200 lb	167 kt max / 48 hrs	General Atomics / Army
	Sentinel RQ-170	USAF	2005	Intel	Est >8,500 lb	UNK	Lockheed Martin
	K-MAX (originally manned)	USMC	2008	6,000 lb external	12,000 lb	80 kt / 267 nm range	Kaman (1)
DoD Current and Near-term UAS - Grp 5	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	Reaper MQ-9	USAF & USN	2007	Hellfire or LGB	10,494 lb	169 kt / 14 hrs	General Atomics (104)
	Global Hawk / Triton R/MQ-4	USAF & USN	~2000	Intel	32,250 lb	310 kt / 32+ hrs	Northrup Grumman (37)

Figure G-3 DoD Current and Near-term UAS – Groups 2 through 5

DoD Developmental UAS (Grp 4)	Name / Designator	Service	IOC	Payload	Max Takeoff	Cruise Spd/ Endurance	Developer (Inventory)
	UCAS X-47B	USN	2020s	4,500 lb in 2 weapon bays	44,567 lb	Mach 0.9+ / 2,100 nm range	Northrup Grumman / USN

Figure G-4 DoD Developmental UAS (Group 4)

G.1 DoD Unmanned Systems Integrated Roadmap

The Unmanned Systems Integrated Roadmap (FY2013-2038)[46] describes the role of unmanned systems to meet the mission and capability needs of Combatant Commanders as follows:

> There are no requirements for unmanned systems within the Joint force, but some capabilities are better fulfilled by unmanned systems. Unmanned systems provide persistence, versatility, survivability, and reduced risk to human life, and *in many cases are the preferred alternatives especially for missions that are characterized as dull, dirty, or dangerous.* With that mindset, unmanned systems are being optimized for these dull, dirty, or dangerous missions:
>
> - Dull missions are ideal for unmanned systems because they involve long-duration undertakings with mundane tasks that are ill suited for manned systems. Good examples are surveillance missions that involve prolonged observation. Unmanned systems currently fulfill a wide variety of “dull” mission sets, and the number will increase in all domains as unmanned systems capabilities improve.
> - Dirty missions have the potential to unnecessarily expose personnel to hazardous conditions. A primary example is chemical, biological, and nuclear detection missions. Unmanned systems can perform these dirty missions with less risk exposure to the operators.
> - Dangerous missions involve high risk. With advances in capabilities in performance and automation, unmanned systems will reduce the risk exposure to personnel by increasingly fulfilling capabilities that are inherently dangerous.

The roadmap summarizes mission and capability needs, technology areas of interest, operating environments, logistics and sustainment challenges, training challenges, and international issues for unmanned air, ground, and maritime systems.

G.2 Navy/Marine

Among the UAVs in the USN/USMC inventory are the RQ-11B Raven, the RQ-12A Wasp, the RQ-20A Puma, the RQ-7B Shadow, the RQ-21A Blackjack, the MQ-8 FireScout, and KMax.

The Raven, Wasp and Puma systems are small man-packable/portable systems used for organic, real-time Reconnaissance, Surveillance and Target Acquisition (RSTA) and Bomb

[46] Department of Defense, “Unmanned Systems Integrated Roadmap (FY2013-2038),” DOD-USRM-2-13, 2013, http://www.defense.gov/Portals/1/Documents/pubs/DOD-USRM-2013.pdf , p20.

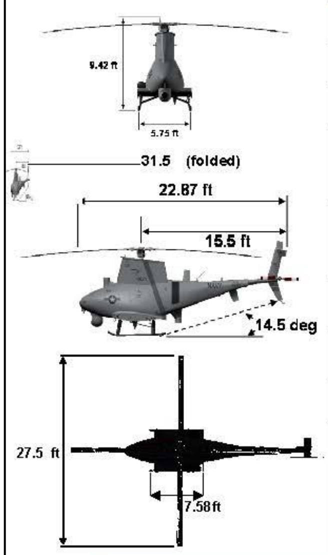
Damage Assessment (BDA) at the small unit (battalion and below) level. Among these, the Raven and Puma systems are also operated by the Army. The Shadow is also deployed by the Army, for ISR missions.

The RQ-21A Blackjack (Figure G-5) is a larger twin-tailed follow-on to the ScanEagle UAS, with a payload capacity of 39 lb. and an endurance of 16 hours. It is currently used for RSTA data collection and dissemination. Standard payloads include day/night full motion video; electro-optical/infrared cameras; mid-wave infrared imager; laser rangefinder; and communications relay. Mission flexibility is allowed by a modular payload bay for payload swap out and integration of advanced payloads. Among the mission system payloads in development for Blackjack are SIGINT, EW and SAR/GMTI. This modular payload feature and the types of modular mission payloads in use or in development are the types of capabilities for the UAVs that complement manned assets envisioned for the distributed functionality system-of-systems concept discussed in section 2.3 of the report.

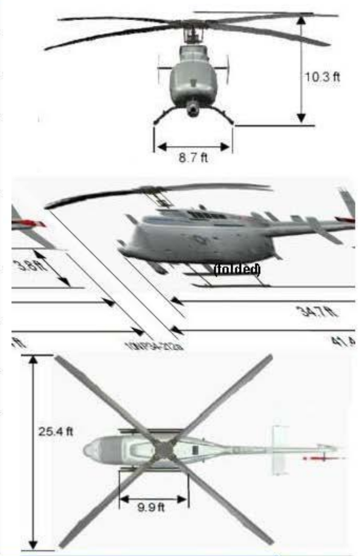
Figure G-5 RQ-21A Blackjack and Launcher on the flight deck of USS Mesa Verde

The USN/USMC operates two unmanned rotorcraft systems, the MQ-8 FireScout and the CQ-24A KMAX. The MQ-8C is a 3000 lb. class unmanned rotorcraft capable of carrying a 300 lb. payload for up to 12 hours (Figure G-6). The KMAX was used by the USMC for unmanned cargo delivery in OEF. It is capable of carrying up to 4500 lb. of payload per sortie (Figure G.2-3). The Army currently lacks a vertical lift UAV for point-of-need sustainment to distributed forces. The KMAX might be able to provide an interim capability until the Army can afford a more tailored solution to this need.

MQ-8 UAV
MQ-8B/MQ-8C Comparison



MQ-8B	Parameter	MQ-8C
85 kts	Maximum Speed	135 kts
80kts	Cruise Speed	115kts
12,500 ft	Service Ceiling	16,000ft
5.5 hrs	Std Day Maximum Endurance (with 300lb payload)	12+ hrs
4.5 hrs	Hot Day Maximum Endurance (with 300lb payload)	10 hrs
2,000 lbs	Empty Weight	3,200 lbs
3,150 lbs	Std Day Fuel & Payload	6,000 lbs
31.5 ft	Length (folded)	34.7 ft
332 lbs (166 lbs/side) 6 APKWS rockets	Weapons Station Load Capacity (300 lbs per side)	600+ lbs (300lb per side)



MQ-8C: 3 ft Longer (folded), 1 ft Taller, 2.5 ft Wider & 1200# Heavier than MQ-8B

Figure G-6 MQ-8 Rotary-wing UAV

Cargo Technology Demonstrator
KMAX (CQ-24A)

- **System deployed Nov 2011 with first flight Dec 2011 (OEF)**
  - Operational oversight fell under Marine VMU squadrons assigned to the Marine Air Wing in theater
  - Deployed with a Government Owned system (including 2 CQ-24A Air Vehicles, Main Operating Base Ground Control Stations (GCSs), and Forward Operating Base GCSs), and 16 contractors
- **Enhancements to operating capability while deployed:**
  - BLOS drop on GPS coordinates
  - Integrated internal auxiliary fuel tank; provided additional range/endurance
  - Incorporated hot refueling capability to provide improved response time
  - Support to retrograde operations
- **Deployment Results**
  - K-MAX system transported over 4.5M pounds of cargo between 17 Dec 2011- 25 Apr 2014 (includes deliveries, retrograde, and training); flying over 2000 sorties
  - 4.5M pounds equates to ~ 509 Twenty Foot Equivalent Units (TEU) ~ (full tractor trailer loads)
- **Future Plans**
  - Move aircraft out to YUMA to support CONOPS, TTPs, CDD development to inform future Cargo POR.
  - Add SATCOM BLOS and HD EO/IR
  - Available to support Army S&T requirements as well USMC

Operational Capabilities

- 85 mi range, 14K alt, 100 kts,
- 4500 lbs cargo per sortie
- Up to 6 sorties per day, 3 drops per sortie
- Primarily flew at night to limit vulnerability

Figure G-7 KMax Cargo Technology Demonstrator

G.3 Air Force

The Air Force vision depicted in Figure G-8 shows the Unmanned Combat Air Vehicle (UCAV) flying in close formation with the F-22, providing "wingman" capabilities utilizing autonomous operations under supervised control of the manned fighter.

Figure G-8 Air Force Vision

The Air Force UAS portfolio focuses on larger platforms (over 1320 lbs):

- MQ-1 Predator/Gray Eagle
- MQ-9 Reaper
- RQ-4A and RQ-4B Global Hawk

The objective of the Low-Cost Attritable Aircraft Program is to develop mission-capable low-cost aircraft concepts and prototypes to validate technologies required for rapid and agile production. The program is scheduled for spiral development with flight demonstrations by FY21.

G.4 DARPA

DARPA has several UAS and/or MUM-T projects, including System of Systems Integration Technology and Experimentation (SoSITE), Collaborative Operations in Denied Environment (CODE), and Aerial Reconfigurable Embedded System (ARES).

Systems of systems aviation architectures, utilizing both manned and unmanned assets which are carefully networked with dispersed functionality, offer the potential to quickly and more effectively respond to a new world of complex mission threat scenarios. This hypothesis is currently being tested at DARPA in the SoSITE program depicted in Figure G-9.

DARPA, through its SoSITE innovative research program, is attempting to demonstrate that a system of systems (SoS) approach can:

1. Provide increased military effectiveness in complex environments,
2. Obtain cost leverage (i.e., the cost of the opponent to counter relative to the cost of the US to deploy), and
3. Enable adaptability necessary to maintain US air superiority in contested environments.

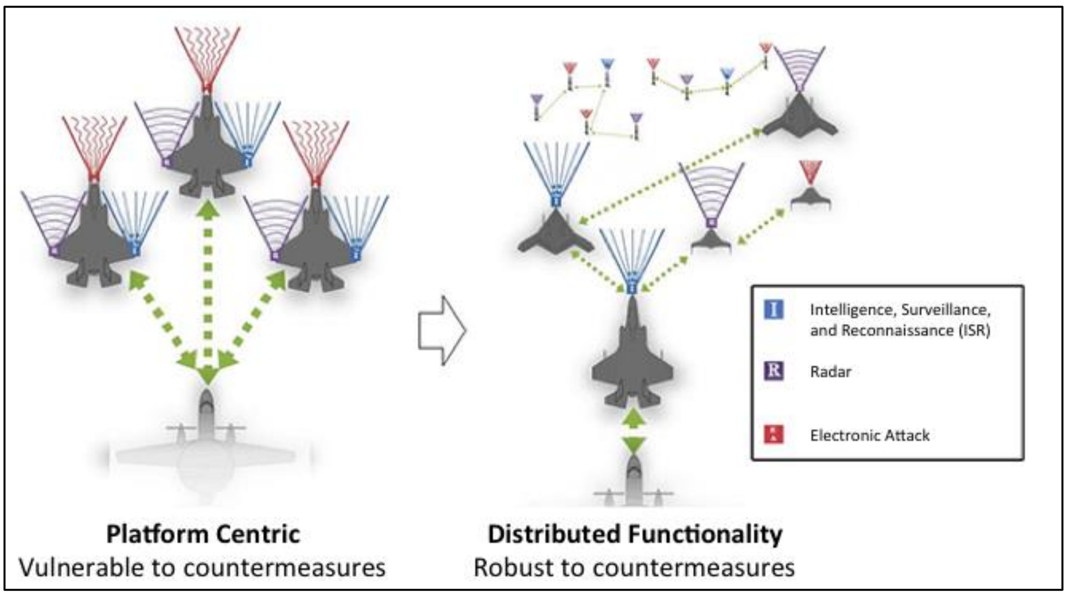


Figure G-9 System of Systems Integration Technology and Experimentation (SoSITE)

The objective of Phase 1 of this DARPA program is to develop architectures for distributing functionality across networks of manned and unmanned platforms for future experimentation, and to develop tools to enable this distribution to be done quickly and reliably. The second phase of the SoSITE program will focus on resolving risks through experiments.

Anti-access, aerial denial (A2/AD) scenarios developed by the DoD are being used as the bases for simulating and evaluating a host of solutions sets using existing, developing and next-generation technologies. Contracts with Boeing, General Dynamics, Lockheed Martin, Northrop Grumman, Apogee Systems, BAE Systems, and Rockwell Collins are experimenting with ways to spread capabilities across a number of manned and unmanned vehicles and weapons to address the future threat scenarios. The SoSITE project encompasses the integration of aircraft, weapons, sensors, and mission systems via the SoSITE open-systems architecture (OSA). The program OSA is based on the open mission systems (OMS) -- an Air Force effort which developed interfaces between mission systems and services connected through an avionics service bus. (The interfaces are based upon a set of open and standardized interface definitions.)

The DARPA Collaborative Operations in Denied Environment (CODE) program depicted in Figure G-10 is another example of research investigating system of system approaches for distributing capabilities among a team of UAVs. This effort is considering how to enable UAVs to work together in teams and take advantage of the relative strengths of each participating unmanned aircraft. The program is specifically looking at expanding the mission capabilities of existing UAVs through increased autonomy and inter-platform collaboration. DARPA’s premise is that collaborative autonomy has the potential to increase capabilities and reduce costs of today's UAVs by composing heterogeneous teams of UAVs that can capitalize on the capabilities of each unmanned aircraft without the need to duplicate or integrate capabilities into each UAV.

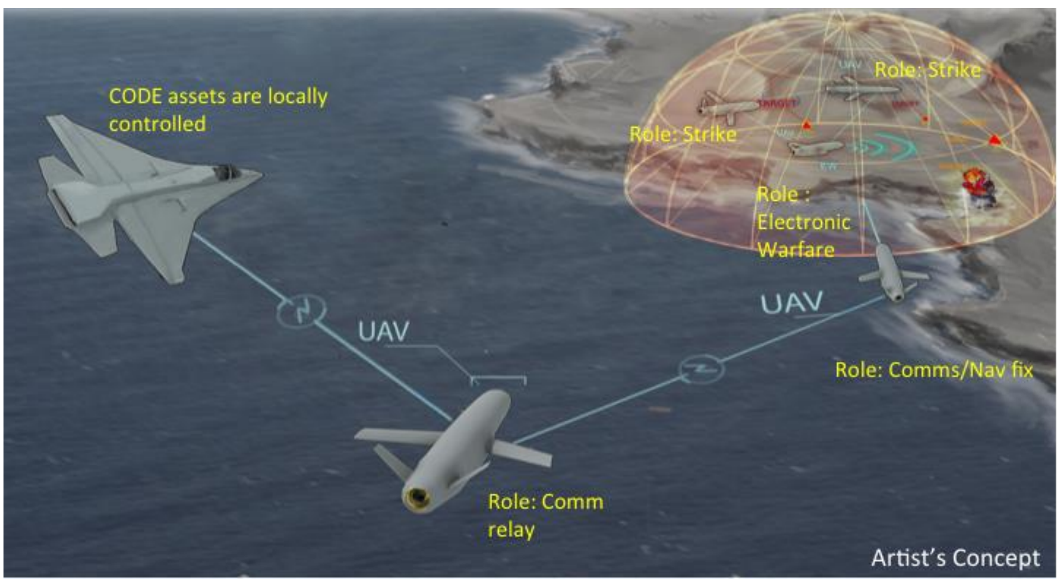


Figure G-10 Collaborative Operations in Denied Environment (CODE)

A SoSITE type approach could have significant utility in Army aviation mission planning. The threat environment for Army aviation is becoming much more complex with a host of different technology threats surfacing (as illustrated in Figure G-11) which include the potential of attack by: cyber, directed energy weapons, sophisticated MANPADS, swarms of UAVs, and the electromagnetic spectrum. A distributed platform/system approach rather than a platform centric design offers the potential of realizing higher survivability under these complex conditions and an increased potential for successful mission execution.

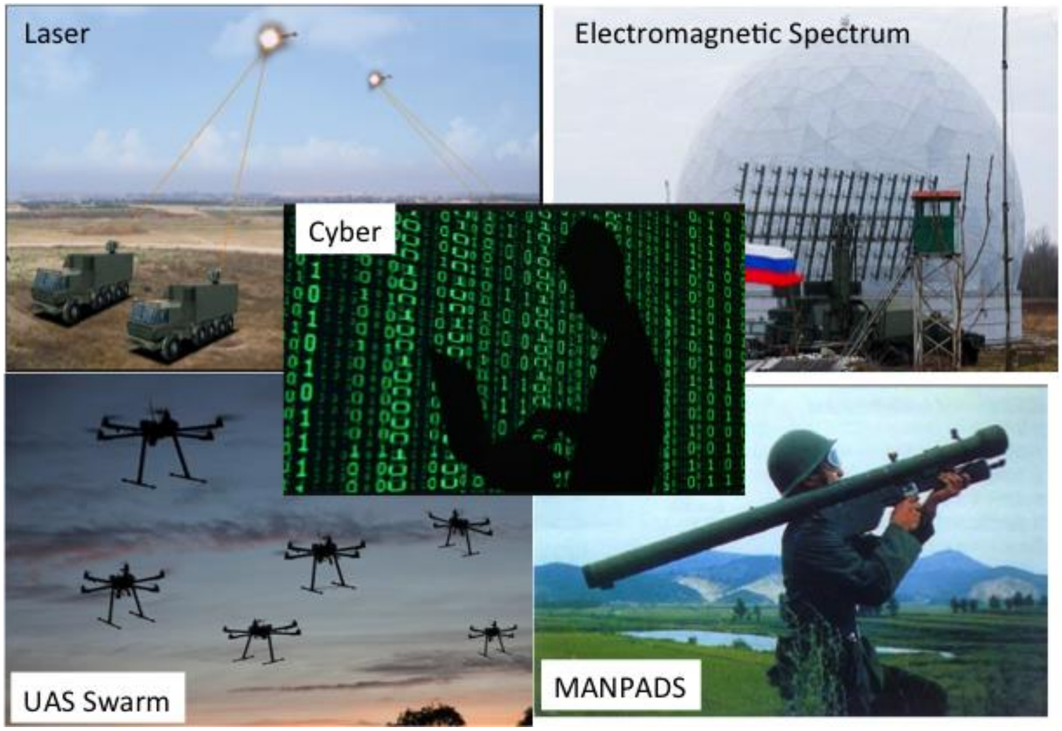


Figure G-11 Complex Threats

The Army's Future Combat System (FCS) had a vision of creating a highly, integrated systems-of-systems network which could flexibly adapt to complex environments. However, after the program's cancellation, the vision of creating distributed system-of-system networks lost priority and a platform-centric approach has largely prevailed. This is evident in the Future Vertical Lift demonstrator programs. There is clearly some good work being done on this effort to reduce program risks associated with a new platform development; however, we see little discussion about how these future platforms can be teamed with other unmanned assets or how functions could be distributed among other platforms to achieve higher potentials of mission success, increased survivability and lower overall lifetime costs.

The panel believes that networked systems studies need to be intensified in the Army especially with regard to aviation mission planning. MUM-T (manned-unmanned teaming) exercises are a first step and are critical to demonstrating such things as interoperability among unmanned systems through the Universal Ground Control Stations and highlighting open architectural approaches that allows multiple control nodes and information access points via the Tactical Common Data Links (TCDL). However, research efforts similar to the SoSITE program at DARPA need to be increased using Army's common open architecture protocols to model and experiment with integration of different technologies and assets in different mission configurations. Other elements such as secure communications technologies, levels of autonomy, common ground controls and operating conditions (visually denied or GPS denied environments) need to be included in these modeling scenarios. The utility of employing unmanned assets used as attritables (Air Force/DARPA construct) should also be considered. While these attritable unmanned systems are not designed to be expendable, meaning that they are not intended to be lost every time they are sent out, they are "attritable," meaning that the operator can afford to "attrit" or lose them, especially when the alternative is the loss of a manned aircraft or an aircrew.

ARES is a vertical takeoff and landing (VTOL) flight module designed to operate as an unmanned cargo platform capable of transporting a variety of payloads. The ARES VTOL flight module is designed to have its own power system, fuel, digital flight controls and remote command-and-control interfaces. Twin tilting ducted fans would provide efficient hovering and landing capabilities in a compact configuration, with rapid conversion to high-speed cruise flight. Lockheed-Martin is the primary performer. The goal is a 7,500 lb vehicle that carries a 3,000 lb payload externally. It can land in a 50x50 ft area. It could be used for MEDEVAC if it is rated to carry humans. Flight test is scheduled for 4Q 2015.

Figure G-12 Aerial Reconfigurable Embedded System (ARES)

G.5 Army Special Operations

In a presentation to the Association of the US Army, BG Erik Peterson, Commanding General, United States Army Special Operations Aviation Command, indicated that the command has more than 300 unmanned air vehicles.[47] In addition to 12 Gray Eagles, 32 Shadows, 224 Ravens, and 7 Pumas, which are Army Programs of Record (PORs), the command uses other vehicles procured in response to joint urgent operational needs (JUONs) and other requests.

Going forward the Army Special Operations team would like fewer types of UAV with more capability, especially multiple sensors on one UAV. Improved processing, exploitation and dissemination is also needed to fully exploit such multi-sensor capabilities.

G.6 NASA

The NASA Aeronautics Six Strategic Thrusts[48] are shown in Figure G-13. The primary thrust for UAS is the Assured Autonomy for Aviation Transformation. In addition, the Real-Time System-Wide Safety Assurance and the Safe, Efficient Growth in Global Operations Thrusts play a role,

[47] Jen Judson, “Army Special Operations Want Multi-Intelligence UAVs,” *Defense News*, 14 January 2016, http://www.defensenews.com/story/defense/land/army-aviation/2016/01/14/army-special-operations-want-multi-intelligence-uavs/78812140/

[48] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: Jay Dyer, “ARMD and Advanced Air Vehicles Program Overview“

especially for the traffic management systems required for eventual integration of UAS into the civilian airspace. NASA's concept for the unmanned traffic management system is key to

- Safely opening new markets, and
- De-confliction with existing vertical flight.

Figure G-13 NASA Aeronautics Six Strategic Thrusts

In addition to the traffic management systems, NASA has created a design environment for the development of novel vertical lift vehicle platforms including significant focus on UAS as shown in Figure G-14.[49] In light of the capability gap identified by the ASB Study Team, Recommendation 3 - UAS Vehicles, these NASA resources should be leveraged as much as possible.

[49] NASA Aeronautics Research Mission Directorate, *AMRD Briefings to ASB,* 9 June 2015: Susan A. Gorton, "Revolutionary Vertical Lift Technology Project Overview"

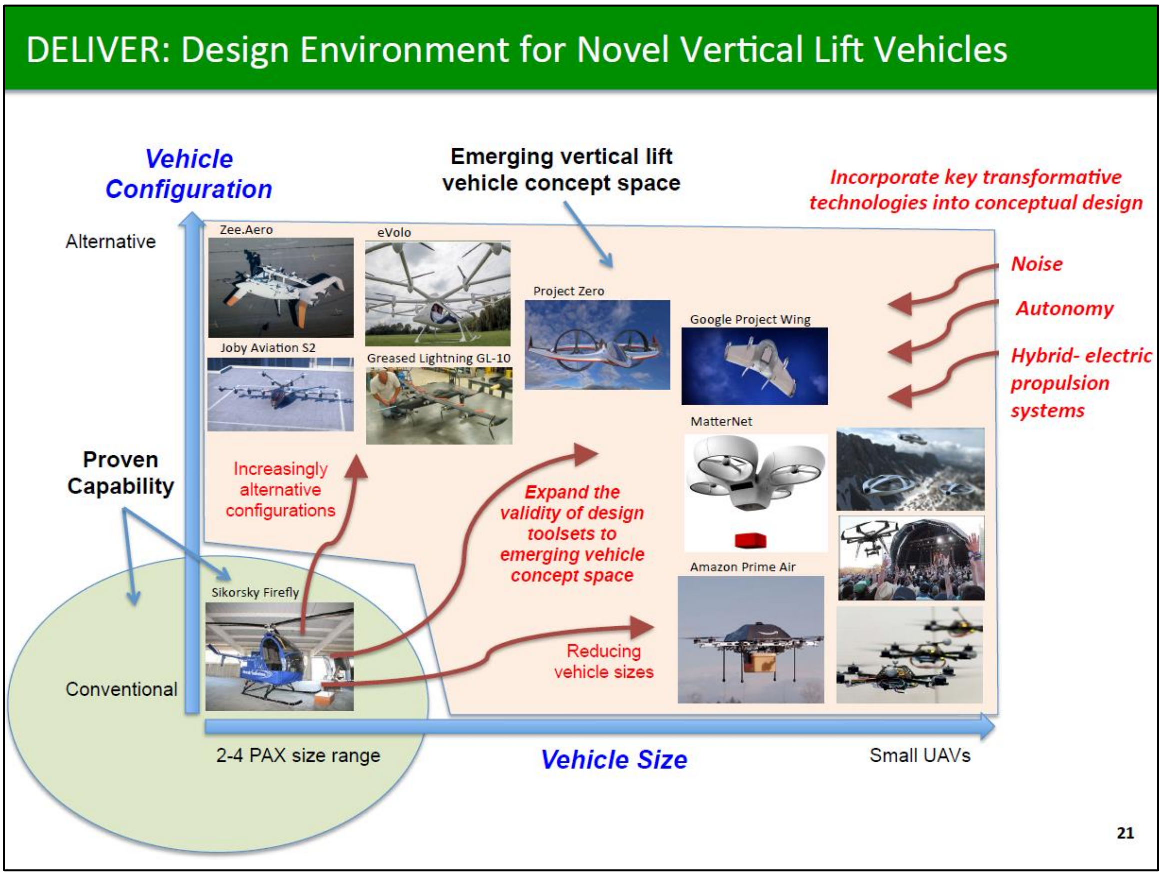


Figure G-14 Design Environment for Novel Vertical Lift Vehicles

G.7 Industry

The US has a healthy UAS industry that spans the gamut from major aircraft companies (i.e., Boeing, Lockheed, Northrop, Sikorsky and Textron) to medium sized companies that specialize in UAS (e.g., General Atomics, Aerovironment, Aurora Flight Sciences) to numerous small innovative companies that provide small UAS, primarily for the commercial market. The investment in UAS and advancement of capabilities through this US-based industrial complex is considerable. However, even with this plethora of activity, the US cannot be assured of asymmetric advantage in UAS systems and capabilities. The rest of the world is also investing in UAS and offer capable systems in the open market. Many of the foreign systems are inexpensive, easy to use, and available to any state or non-state adversary.

APPENDIX H LARGE-SCALE TEST FACILITIES RELEVANT TO ARMY AVIATION

The Army Aviation RDECOM community (AMRDEC and ARL) has established numerous facilities at locations in Virginia and California in support of Army Aviation. Figure H-1 describes the large-scale AMRDEC facilities used for ballistics testing, aerodynamics, countermeasures, large rotor testing, structural testing, and transonic dynamics.

Figure H-1 Key Test Facilities Relevant to Army Aviation

These AMRDEC facilities are unique and provide important capabilities needed to further Army Aviation. These key test facilities, along with other relevant facilities, are described briefly below.

Wind Tunnels:

- National Full-Scale Aerodynamics Complex (NFAC), Moffett Field, CA: Advanced testing of full-scale rotorcraft; 40-by-80 foot wind tunnel circuit is capable of providing test velocities up to 300 knots. The 80-by-120 foot test section is the world's largest wind tunnel and is capable of testing a full-size Boeing 737 at velocities up to 100 knots.
- 7-by-10 foot Wind Tunnel, Moffett Field, CA: Scaled subsonic aerodynamic research.
- Transonic Dynamics Tunnel, Hampton, VA: Helicopter performance loads and stability testing; world's premier wind tunnel for testing large aeroelastically scaled models at transonic speeds.

Other Major Facilities:

- Ballistics Test Facility, Ft. Eustis, VA: Fuel tank testing up to 30 mm ammunition.
- Countermeasures Test Facility, Ft. Eustis, VA: Acoustic/infrared radiation measurement of turbine engines and suppression devices.
- Structural Test Facility, Ft. Eustis, VA: Rotor-blade root end fixture for loads and fatigue testing; rotor-blade mid-span fixture for loads and fatigue testing; Rotor-Full Scale Dynamics Test Facility.
- Large Rotor Test Apparatus (in NFAC), Moffett Field, CA; Full scale rotorcraft component testing.

Other Key Facilities:

- Rapid Prototyping Facility (RPF), Ft. Eustis, VA: Rapid prototyping of aircraft modifications and developmental test hardware.
- Prototype Integration Facility (PIF), Redstone Arsenal, AL: Multi-discipline facility for fabricating and integrating developmental and operational test hardware and systems for AMRDEC and other customers.
- Advanced Prototype Experimentation (APEX), Redstone Arsenal, AL: Warfighter-in-the-loop simulation facilities for missile, aviation and unmanned systems.
- Aviation System Integration Facility (ASIF), Redstone Arsenal, AL: Avionics & software development integration & testing in a Common Avionics Architecture System (CAAS) and Future Airborne Capability Environment (FACE) based SIL.
- Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL), Moffett Field, CA: Full-authority variable-stability JUH-60 Black Hawk.
- RASCAL Development Facility, Moffett Field, CA: Ground-based hardware-in-the-loop simulation facility to check out ``experimental'' code before flying on RASCAL.
- RMAX, Moffett Field, CA: two Yamaha RMAX helicopters used for OFN/SLAD autonomy research.

Figure H-2 shows the facilities key to the foundational science work conducted by ARL in the areas of rotorcraft survivability, scientific visualization, materials, robotics, electromagnetics, and propulsion.

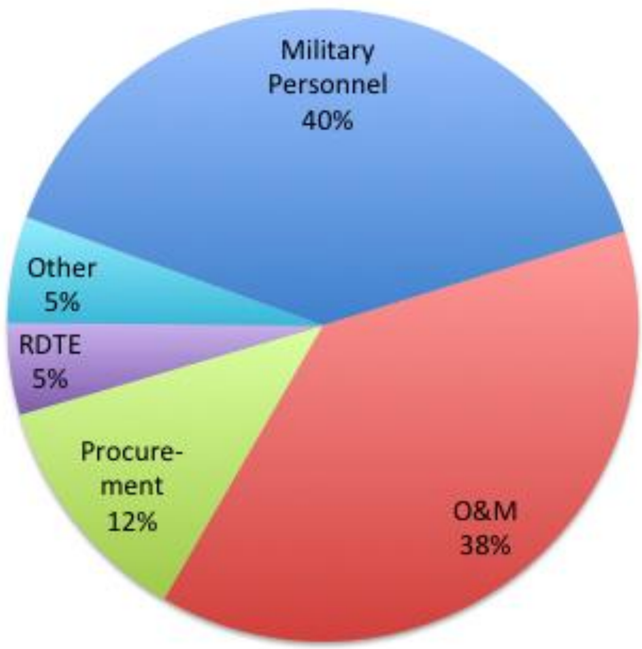
Figure H-2 Key ARL Facilities for foundational science and engineering work that support Aviation

APPENDIX I ARMY AVIATION FUNDING

Data in this Appendix is taken from FY16 budget justification documents at http://www.asafm.army.mil/offices/BU/BudgetMat.aspx?OfficeCode=1200 in Sept 2015.

I.1 Army Total Obligation Authority

The President's Budget funding request for FY16 includes $126.4B base funding plus $20.7B overseas contingency operations (OCO) funding. Those funds are distributed across major funding areas as shown in Figure I-1.



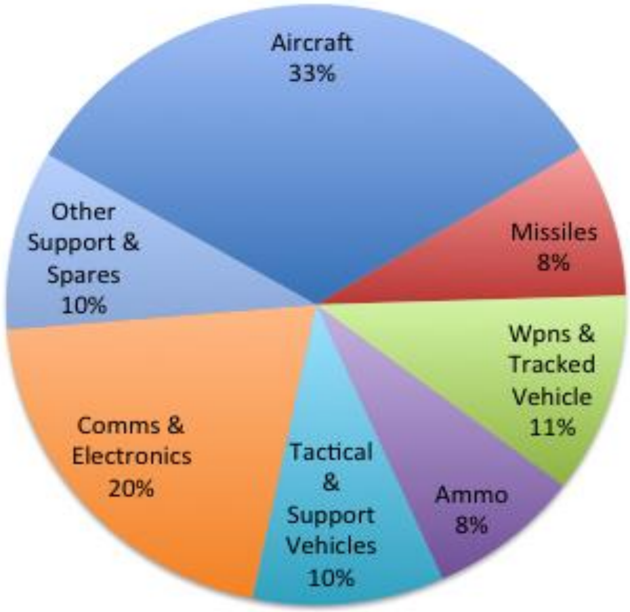
FY16 (B$)	Base	OCO	Total
Military Personnel	56.3	2.0	58.3
O&M	44.7	11.5	56.2
Procurement	16.1	1.6	17.7
RDTE	6.9	0.0	6.9
Other	2.4	5.6	8.0
Total	126.4	20.7	147.1

Figure I-1 Distribution of Army TOA Requested for FY16 ($147.1B)

While some of the funding for military personnel and operations & maintenance (O&M) supports Army aviation, the budget documents do not provide sufficient detail to identify those funds separately. The documents do identify procurement funds for aircraft. They also provide sufficient description of RDT&E efforts to estimate aviation funding. Other funding (military construction, family housing, BRAC, Chemical Agents and Munitions Destruction, Army Working Capital Fund, Arlington National Cemetery, and OCO passthrough/transfer) does not appear to directly support aviation.

I.2 Army Procurement Funding

Figure I-2 shows the distribution of Army procurement funding requested for FY16; $5.9B of the $17.8B (33% of the total) is allocated to aircraft systems. This includes funding for purchase of aircraft (fixed wing and rotary wing), modification of aircraft, and support equipment & facilities.



FY16 (B$)	Base	OCO	Total
Aircraft	5.7	0.2	5.9
Missiles	1.4	0.0	1.5
Weapons & Tracked Combat Vehicle	1.9	0.0	1.9
Ammunition	1.2	0.2	1.4
Tactical & Support Vehicles	0.8	1.0	1.8
Communication & Electronics	3.5	0.1	3.6
Other Support Equipment & Spares	1.6	0.1	1.7
Total	16.1	1.6	17.8

Figure I-2 Distribution of Army Procurement Funding Requested for FY16 ($17.8B)

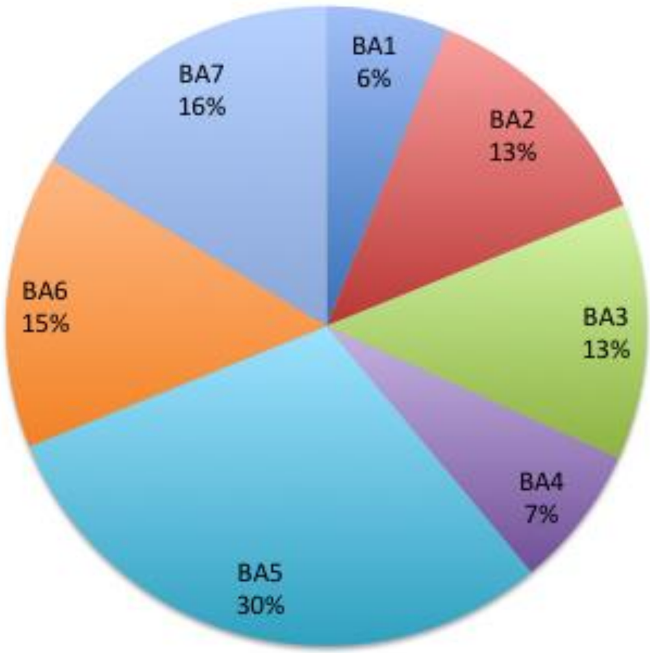
I.3 Army RDTE Funding

RDTE funds are allocated in program elements and projects within seven budget activities:

- Budget Activity 1, Basic Research: Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind.
- Budget Activity 2, Applied Research: Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met. It is a systematic application of knowledge toward the production of useful materials, devices, and systems or methods.
- Budget Activity 3, Advanced Technology Development: Includes all efforts that have moved into the development and integration of hardware for field experiments and tests. Projects in this category have a direct relevance to identified military needs.
- Budget Activity 4, Demonstration and Validation. Dem/Val includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
- Budget Activity 5, Engineering and Manufacturing Development: EMD includes those projects in engineering and manufacturing development for Service use but which have not received approval for full-rate production.
- Budget Activity 6, RDT&E Management Support: Includes R&D effort directed toward support of installations or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, O&M of test aircraft and ships, and studies and analyses in support of the R&D program.
- Budget Activity 7, Operational System Development. Includes those development projects in support of development acquisition programs or upgrades still in EMD, but

which have received Defense Acquisition Board (DAB) or other approval for production, or production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.

Figure I-3 shows the distribution of funds in the FY16 budget request. Only a very small amount of OCO funding is requested for the RDTE accounts.



FY16 (M$)	Base	OCO	Total
BA1	425.1	0.0	425.1
BA2	879.7	0.0	879.7
BA3	895.7	0.0	895.7
BA4	498.7	1.5	500.2
BA5	2,069.0	0.0	2,069.0
BA6	1,027.5	0.0	1,027.5
BA7	1,129.3	0.0	1,129.3
Total	6,925.0	1.5	6,926.5

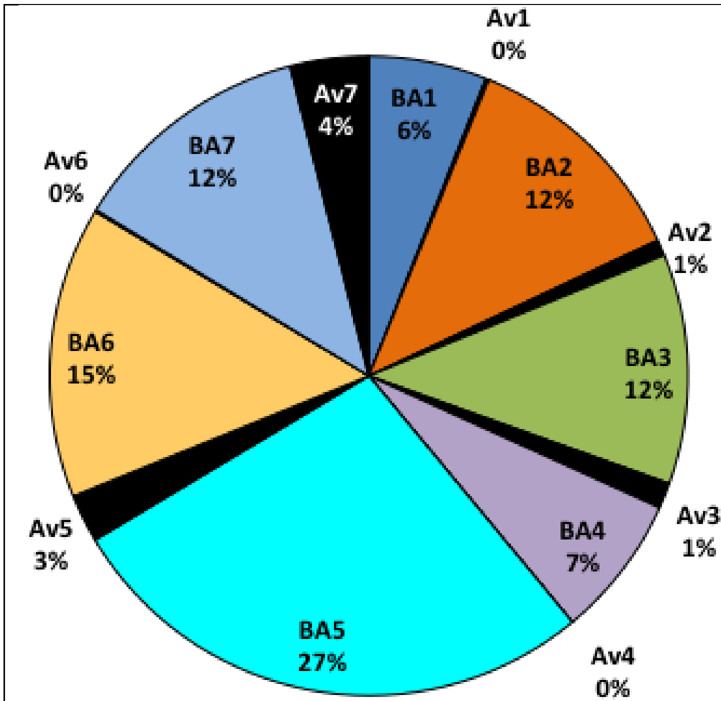
Figure I-3 Distribution across Budget Activities of RDTE Funding Requested for FY16 ($6.9B)

RDTE budget documents provide sufficiently detailed descriptions to permit estimating the funding allocated to aviation within each budget activity. Figure I-4 shows, for each Budget Activity, the estimated amount of funding supporting Army aviation. The black wedge shown clockwise from each budget activity represents the aviation funding, 8.8% of the Army RDTE total. Note that the aviation RDTE funding totals $609M, slightly more than 1/10 of the aviation Procurement funding.

The largest component of RDTE aviation funding is in BA7, Operational System Development. Over 80% of that funding is allocated to Apache, Blackhawk, and Chinook Product Improvement Programs and the Improved Engine Turbine Program (ITEP).

The next largest component is in BA5, Engineering and Manufacturing Development, with over half of that funding allocated to the Joint Air-to-Ground Missile (JAGM) designed to replace the Hellfire and LONGBOW aviation missiles.

The Science and Technology Budget Activities, BA1-BA3, include $158M for aviation, a little over 7% of the total. These activities are discussed further in the next section.



FY16 (M$)	Non-Aviation	Aviation	% Aviation
BA1	413.5	11.6	2.7%
BA2	822.8	56.9	6.5%
BA3	806.0	89.7	10.0%
BA4	500.2	0.0	0.0%
BA5	1,900.0	168.9	8.2%
BA6	1,021.1	6.4	0.6%
BA7	853.9	275.4	24.4%
Total	6,317.5	608.9	8.8%

Figure I-4 RDTE Funds Requested for Aviation

I.4 Army S&T Funding

For Budget Activity 1, Basic Research, budget documents do not provide detailed breakdowns of the planned efforts. Some projects such as the Vertical Lift Research Centers of Excellence clearly support aviation. Others are more general and cannot be linked to specific technologies.

Budget Areas 2, Applied Research, and 3, Advanced Technology Development, support more specific projects that can be linked to aviation or other areas. Approximately 8.3% of Army BA2 and BA3 supports Army aviation. Estimates can also be made of which activities within aviation are supported. Figure I-5 shows estimates for FY16 BA2/3 requests. The largest portion supports the Joint Multi-Role Technology Demonstration. The Degraded Visual Environment (DVE) effort also receives significant support.

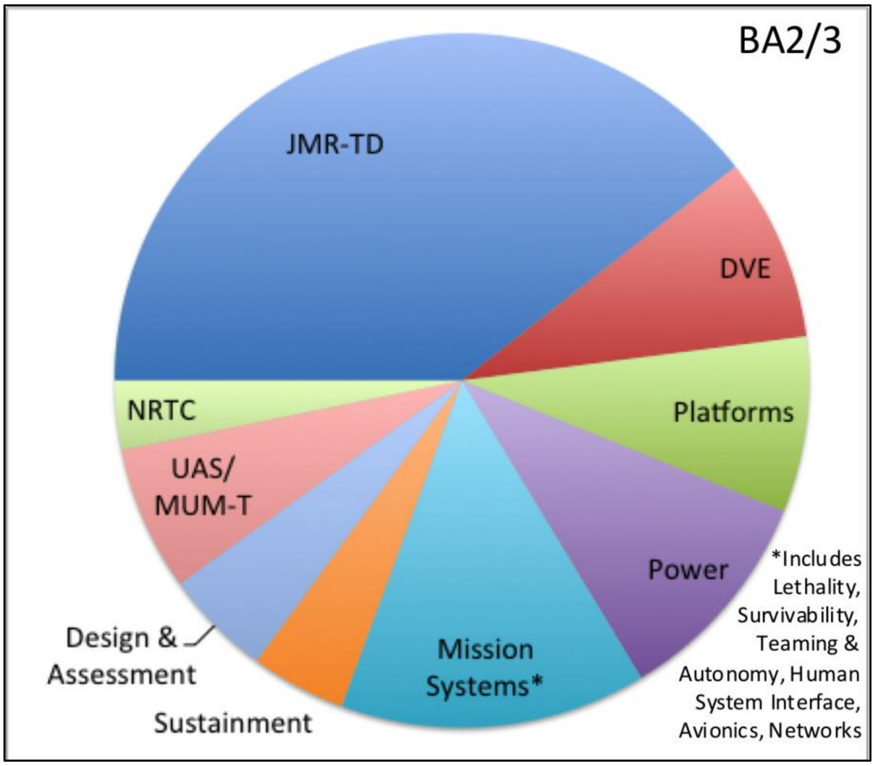


Figure I-5 Efforts Supported by Aviation BA2 and BA3 Funds

APPENDIX J ASB APPROVED BRIEFING WITH FINDINGS AND RECOMMENDATIONS

Future of Army Aviation

Summer Study Outbrief

07/16/15

Army Science Board 1

Agenda

- Introduction: Team, Terms of Reference (TOR)
- TOR Task 1: Review S&T, Modernization Plans, Developments and Force 2025 and Beyond Campaign
- TOR Task 2: Innovative Technologies & Focus Areas with Findings and Recommendations
- TOR Task 3: Feasibility & Risk Assessment

Army Science Board 2

Study Team

1. Dr. Ron Sega (MG-Ret) (Chair)
2. Dr. Mark Glauser (Vice Chair)
3. Dr. Nancy Chesser
4. Mike Heinz
5. Grant Hollett (RADM-Ret)
6. Tom Ramos
7. Teresa Smith
8. Dr. Bill Snowden
9. Dr. Alan Willner

Red Team Advisor: George Singley
Study Manager: Maj Andy Brown

Sponsor: G-3/5/7

Army Science and Technology for Army Aviation 2025-2040

TOR Objective

Identify and assess S&T enhancements capable of being fielded during the **2025-2040** timeframe that will:

- increase Army Aviation's expeditionary capabilities to support full-spectrum military operations, and
- reduce its sustainment tails and logistics footprint.

TOR Has Three Tasks

1. **Review** current Army, Navy/USMC, Air Force, DARPA, OSD, NASA and industry aviation S&T **plans, modernization plans and ongoing developments**, as well as relevant Force 2025 and Beyond Campaign activities.
2. Address the use of **innovative technologies** that increase capabilities, overall mission effectiveness, survivability and lethality while reducing sustainment requirements, including logistics footprint and frequency of resupply.
   Include, but not necessarily be limited to, the following key focus areas for improvement:
   - near-zero maintenance platforms and systems,
   - exploitation of unmanned aircraft systems,
   - meeting the challenges of emerging threats,
   - enhancing the ability to operate worldwide in a variety of stressing and degraded visual conditions.
3. Determine the **feasibility and risks** associated with each of the findings and recommendations.

Army Science Board 5

Over 30 Team Visits

- **Army**
  - AMRDEC Aviation Development Directorate (ADD)
  - PEO Aviation and PMs
  - USA Aviation Center of Excellence (USAACE)
  - USA Aeromedical Research Laboratory (USAARL)
  - Combat Readiness/Safety Center
  - TRADOC Capability Managers (UAS, Lift)
  - CERDEC
  - Army Research Laboratory
  - Army Special Operations Aviation (ARSOA)
- **Other Services**
  - Navy - NAVAIR
  - Air Force - AFRL
- **Joint**
  - Future Vertical Lift IPTs
  - DARPA
- **Other**
  - NASA HQ
  - NASA Langley
  - NASA Ames
  - Army Aviation Association of America (Quad-A) Summit
  - Industry

Army Science Board 6

Extensive Literature Survey (Partial List)

- **Army**
  - Army Equipment Program in support of Presidents Budget 2016
  - 2014 Army Aviation S&T Strategic Plan (ASSP)
  - 2014 Army Equipment Modernization Plan
  - ARCIC Executive Summary Unified Quest 2014
  - TRADOC Pamphlet 525-7-15 Army Aviation Operations 2015-2024
  - TRADOC Pamphlet 525-8-5 Army Functional Concept for Engagement
  - FM 3-04 Army Aviation
  - RDECOM Strategic Plan 2015-2040
  - Budget Documents FY01-FY16
  - Force 2025 and Beyond Oct 2014
  - UAS Roadmap 2010-2035
  - Army Vision: Strategic Advantage in a Complex World
  - Force 2025 Maneuvers White Paper, 2014
- **DoD**
  - 2015 National Security Strategy
- **JROC**
  - Future Vertical Lift (FVL) Capability Based Assessment (CBA), 21 Jun 10
  - FVL Family of Systems (FoS) Initial Capabilities Document (ICD), 8 Apr 13
  - Joint Future Vertical Lift (JFVL) ICD, Oct 09
  - Joint Heavy Lift (JHL) ICD, 12 Oct 07
  - Unmanned Systems ICD, 14 May 10
  - Aircraft Survivability CBA, 6 Jan 09
  - Degraded Visual Environment CBA, Jul 09
  - Aircraft Survivability ICD, 6 Oct 11
- **Navy/USMC**
  - 2015 Marine Aviation Plan
  - FY14 Navy Science and Technology Objectives
  - Naval Aviation Vision
  - Sea-Based Aviation – A National Naval Responsibility
- **DSB**
  - Future Needs for VTOL/STOL Aircraft, 2007

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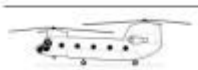
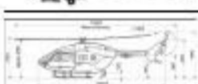
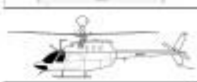
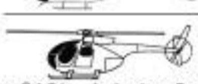
Legacy Rotorcraft

Legacy Army Rotorcraft	Name / Designator	Role	IOC/ Retire?	Status	Max Takeoff	Max Load	Speed/ Range	Developer (# built)
	Chinook CH-47D/F	Cargo	1962 / 2060	Block II in 2020	50,000 lb	28,000 lb	170 kt / 400 nmi	Boeing (~1,200)
	Black Hawk UH-60	Utility	1979 / 2060	Upgrades + ARI transfer*	23,500 lb	2,640 lb int, 9,000 lb ext	159 kt /	Sikorsky (~4,000)
	Apache AH-64	Attack	1984 / 2060	Upgrades + ARI transfer*	23,000 lb		158 kt / 257 nmi	Hughes (~2,000)
	Lakota UH-72	Trainer, CONUS only	2006 / ???	ARI use for training	7,900 lb	3,950 lb	145 kt / 370 nmi	Eurocopter (~300)
	Kiowa OH-58D	Observa-tion	1969 / soon	ARI retire*	5,500 lb	1,700 lb	120 kt / 260 nmi	Bell (~2,200)
	Little Bird MH-6	SOF	1980 / ???		3,100 lb	1,500 lb (6 pax)	152 kt / 232 nmi	McDonnell Douglas / Boeing

*ARI = Aviation Restructuring Initiative proposed by Army

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Legacy UAS & Fixed WIng

Legacy Army UAS	Name / Designator	Role	IOC	Payload	Max Takeoff	Speed/ Endurance	Developer (# built)
	Raven RQ-11A/B	Small UAV, Hand launch	1999	ISR	4 lb	24-50 kt / 1-1.5 hrs	Aero-Vironment (19,000+)
	Puma RQ-20A		2007	ISR	13.5 lb	20-45 kt / 3.5 hrs	Aero-Vironment (1,000+)
	Shadow RQ-7A/B	Short Range Tactical	2002	ISR	375 lb	110 kt / 9 hrs	AAI Corp (~100+)
	Gray Eagle MQ-1C	Predator Upgrade	2009	ISR Pod / Hellfire	3,600 lb	150 kt / 30 hrs	General Atomics (~100)

Fixed Wing: Over 339 aircraft – all commercial derivative aircraft
Three categories: Special Electronic Mission Aircraft (SEMA), Transport Aircraft:, Mission Support Aircraft

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FM 525-3-1 Army Operational Concept: Win In A Complex World

- Respond Globally: "When called upon, globally responsive combined arms teams ***maneuver from multiple locations*** and domains to present multiple dilemmas to the enemy..."
- Conduct Joint Combined Arms Operations: "Joint combined arms operations create multiple dilemmas for the enemy. Army forces ***achieve surprise*** through ***maneuver across strategic distances*** and arrival at unexpected locations. Army forces have the mobility, protection and firepower necessary to strike the enemy from unexpected directions. In high ***anti-access and area denial*** environments, ***dispersion*** allows future army forces to evade enemy attacks, deceive the enemy and achieve surprise."
- Sustain High Tempo Operations: "Army sustainment units integrate efforts with Joint Force to ensure unimpeded sustainment flows across land, air and maritime domains. These units provide supplies and services to the ***point of need..***."

Operational maneuver and sustainment to point of need of dispersed forces

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Complex Threats and Opportunities

Army Science Board 12

Unified Quest 2014 Conclusions

- “Self-deployable Army future **vertical lift** capabilities and joint shallow draft systems must be capability development options. These capabilities are **essential** to future strategic, operational, and tactical maneuver and enable dispersed forces to maintain mutually supportive functions.”
- **“Unmanned** air and ground platforms that enhance soldier decision-making and action with self-planning, self-navigation, and mission execution capabilities will have significant potential to change the future battlefield. The Army must develop concepts of employment for future autonomous and unmanned systems in the near-term to integrate them efficiently into the force in the far-term (2030-2040).”

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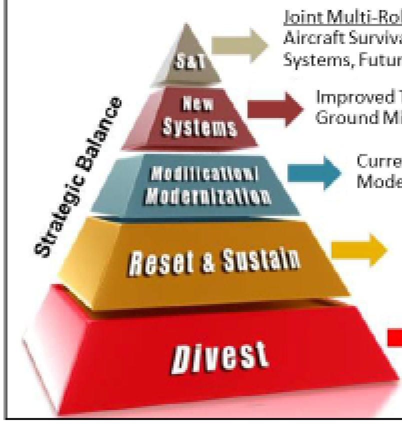
Army Aviation Modernization Strategy

Invest in essential technologies that have a high likelihood of successful transition to Affordable programs, to help close capability gaps in a resource constrained environment. Incrementally upgrade Aviation platforms, divest old systems and invest in new platforms and technologies, in order to maintain modernized aircraft that can defeat **new and increasingly complex threats.**



- S&T: Joint Multi-Role Tech Demonstrator, Degraded Visual Environment, Aircraft Survivability Equipment, Future Family of Unmanned Aircraft Systems, Future Affordable Turbine Engine
- New Systems: Improved Turbine Engine Program, Future Vertical Lift, Joint Air to Ground Missile, Common Infrared Countermeasure
- Modification/Modernization: Current Attack, Utility, Cargo, and Unmanned Aircraft System Modernization and digitization
- Reset & Sustain: Sustain legacy variants of the Army's Attack, Utility, Light Utility, Cargo and munitions inventories during ongoing modernization efforts
- Divest: Aviation Restructuring Initiative: Divest outdated Single engine scout and training aircraft as well as Cargo and utility aircraft that have exceeded their Useful life

Source: Army Equipment Modernization Strategy, March 2015 (Annex E – Aviation) - G8

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Joint Multi-Role Tech Demo (JMR-TD)

- JMR-TD is cost sharing effort between Army and Vendors. Four vendors selected Oct 2013 to begin design for vehicle demonstrator:
  - AVX – coaxial-rotor, ducted-fan compound helicopter
  - Bell – tilt rotor
  - Karem - variable-speed tilt rotor
  - Sikorsky Boeing – coaxial rigid-rotor, pusher-propulsor design

- Down-selected Aug 2014 to Bell "V-280 Valor" and Sikorsky-Boeing "Defiant" to build demonstrators for 2017 flight. AVX and Karem funded for tech development.
- Both JMR TD variants use existing engines (Bell – CH-53, Sikorsky – CH-47)

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Future Vertical Lift Family of Systems

- FVL FoS is a Joint **initiative**, not yet a **program**, to develop a 5-class family of rotorcraft for DoD (light, medium, heavy).
- Although requirements are still being refined, the notional concept for a new aircraft must:*
  - reach speeds of 230 knots
  - carry up to 12 troops
  - Operate in "high-hot" conditions at altitudes of 6,000 ft and temperatures of 95-degrees Fahrenheit,
  - have a combat radius of 263 mi with an overall unrefueled range of 527 mi
  - have optionally piloted or supervised autonomous flight capabilities
- Mission sets include: cargo; utility; armed scout; attack; humanitarian assistance; medical evacuation; anti-submarine warfare; anti-surface warfare; land/sea search and rescue; special warfare support; vertical replenishment; airborne mine countermeasures.

Source: Army Propels Next Generation of Helicopter Program Forward, DefenseTech, Oct 2014 (http://defensetech.org/2014/10/08/army-propels-next-generation-helicopter-program-forward/)

Army Science Board 16

Navy and Air Force Have Visions for UAS

SECNAV: "F-35C should be Navy's last manned strike jet" 4/16/15

General Impressions Gained From Review

- **Army manned aviation S&T:** Generally well balanced (e.g. JMR-TD & FVL)
- **Outside investments:** NASA, USAF, USN/USMC, DARPA and industry have promising innovative technology and concepts that could be leveraged
- **Survivability**: Sophisticated threats place Army aviation assets at high risk. These threat capabilities are growing and proliferating.
- **Architecture**: Survivability against 2025+ threats will require system of systems (SoS) solutions that exploit the power of collaborative manned-unmanned teaming (MUM-T). The operational and system architectures and CONOPS for these SoS solutions have not been defined.
- **Unmanned Systems**: Army aviation requires a strong vision for the expanded use of UAS. Currently, there is neither the vision nor the funding to exploit the potential of UAS, autonomy and MUM-T
- **Manned Systems**: Legacy manned systems are 1970 vintage designs. Next generation systems (FVL) are scheduled for IOC in mid 2030s.
- **Maneuver**: Army CONOPS requires expeditionary and operational maneuver of dispersed mechanized forces. Army aviation assets cannot satisfy this need.
- **Army Aviation RDT&E Budget**: Inadequate to meet future aviation challenges. FVL is not funded; industrial base is eroding.

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TOR Task 2: Innovative Technologies & Focus Areas with Findings and Recommendations

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Findings & Recommendations Overview

Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

Addressing Capability Gaps: Development and Acquisition

3. UAS Vehicles
4. Modernization of Legacy Rotorcraft Systems
5. FVL Acquisition with Speed and Simplicity
6. Aviation Mission Systems
7. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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1. System of Systems Operational Effectiveness Analyses

Findings

- Increasing threat sophistication and proliferation (e.g., missiles, UAS, cyber, and directed energy) pose critical concerns. (Classified annex provides additional details)
- Platform-centric survivability must evolve to a manned-unmanned system-centric approach with new CONOPS and TTPs.
- A system of systems architecture should include manned-unmanned teaming, supervised autonomous systems, and secure communications.

Recommendation

- TRADOC: Conduct operational effectiveness analyses of potential system of systems concepts in a cost-constrained environment that address capability gaps for Army aviation in 2025 and beyond in complex threat environments. Concepts should include holistic air-ground approaches, high/low mixes of collaborative manned/unmanned systems, FVL performance characteristics, higher levels of autonomy, PNT in denied GPS environments, attritable UAS assets and enhanced lethality of DE. Develop CONOPS and architectures for the most cost effective concepts.

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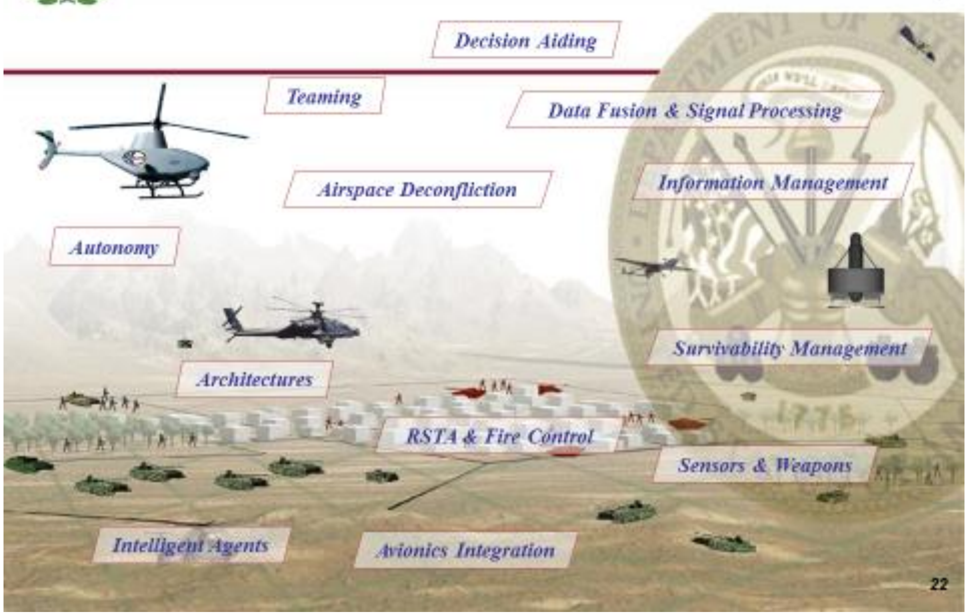
Integrated Battlespace



2. Affordability of Heavy Vertical Lift (HVL)

Findings

- Heavy vertical lift (20-30 stons) is required by the Army CONOPS for expeditionary and operational maneuver, validated by JROC (documented in the FVL and JHL ICDs) and supported by Unified Quest 2014, and "2012 Gaining and Maintaining Access: An Army-Marine Corps Concept."
- However, development of a new system is cost prohibitive within likely future Army modernization (RDA) funding before 2040.
- Interim solutions able to provide more limited capability are available (e.g., CH-53K at 18 stons, and Joint Precision Air Drop System – JPADS) and could provide viable options.

Recommendation

- TRADOC: Assess interim and future HVL options for meeting Army CONOPS and documented JCIDS capability needs for expeditionary and operational maneuver and recommend road ahead
  - If development of HVL is cost prohibitive, consider alternatives.
  - If there are no plans for HVL, do not assume it is available in analyses, wargames, and exercises.

Historical Heavy Vertical Lift Options

Findings & Recommendations Overview

Context: Character of Warfare in 2025 and Role of Army Aviation

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

Addressing Capability Gaps: Development and Acquisition

3. UAS Vehicles
4. Modernization of Legacy Rotorcraft Systems
5. FVL Acquisition with Speed and Simplicity
6. Aviation Mission Systems
7. Aviation Systems Integration and Testbed

S&T Portfolio: Innovation and Game Changers

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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3. UAS Vehicles

Findings

- The USN/USMC and USAF have strong visions for the expanding role of UAS and manned-unmanned teaming in aviation missions.
- DARPA, USN/USMC and USAF are investing in next generation UAS technology options that offer potential capability for Army aviation.
- New UAS are needed to fully exploit manned–unmanned synergy and collaboration of manned systems with supervised autonomous systems within a system-of-systems architecture.

Recommendation

- ASA(ALT): Revise UAS Roadmap to expand near-term and future UAS vehicle options, some of which should be compatible with speed, hover, and range of current and future manned aircraft, with attributes compatible with distributed functionality among UAS (ISR, Lethality, ...) as informed by the results of system of systems operational effectiveness analyses (Recommendation 1)

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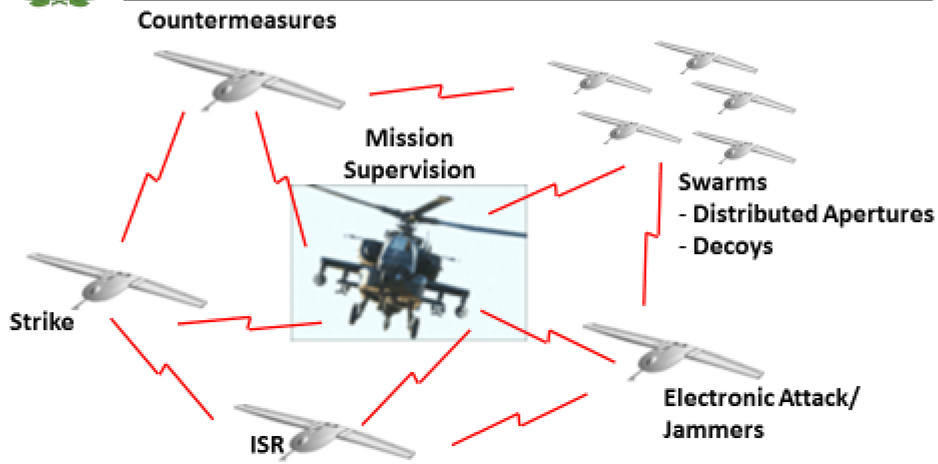
Distributed Functionality Collaborative System of Systems Concept



Low End Single Function Unmanned Systems
Complement and Expand Capability of High End System

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4. Modernization of Legacy Rotorcraft Systems

Findings

- Legacy rotorcraft systems (AH-64, CH-47 and UH-60) are expected to remain deployed until at least 2060, requiring modernization investment.
- Within the current limited budget, Army aviation S&T is investing in technologies that apply to both legacy and future manned systems.
- These technologies include: ITEP/FATE engine insertion, DVE capabilities, CBM/PHM capabilities, ASE improvements, and greater MUM-T.

Recommendation

- ASA(ALT): Continue S&T and road-mapping efforts for modernizing legacy systems with emphasis on those technologies that are also applicable to future vehicles, as informed by the results of system of systems operational effectiveness analysis (Recommendation 1).

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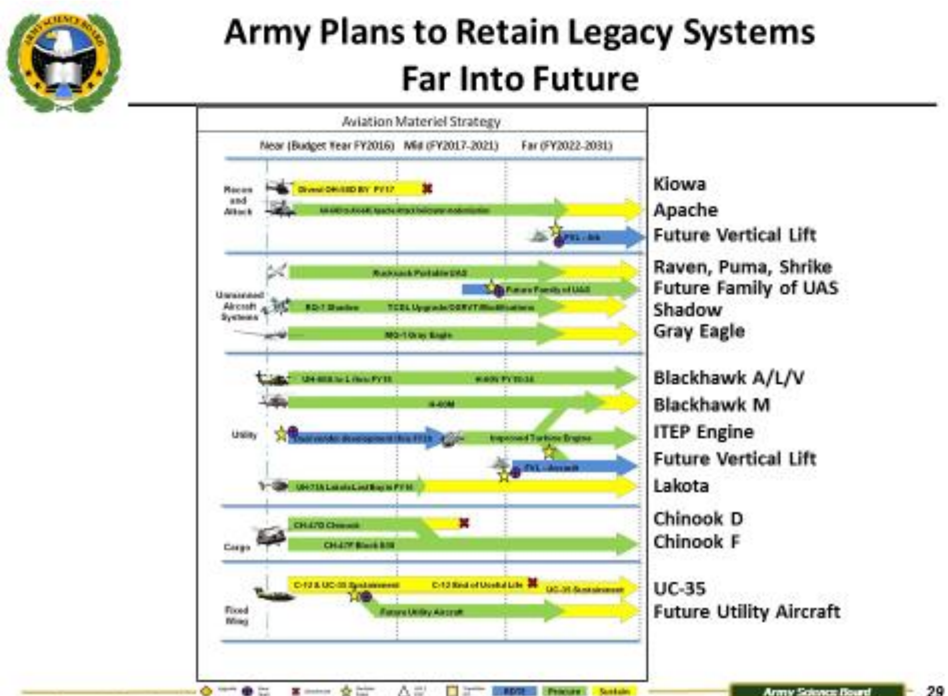
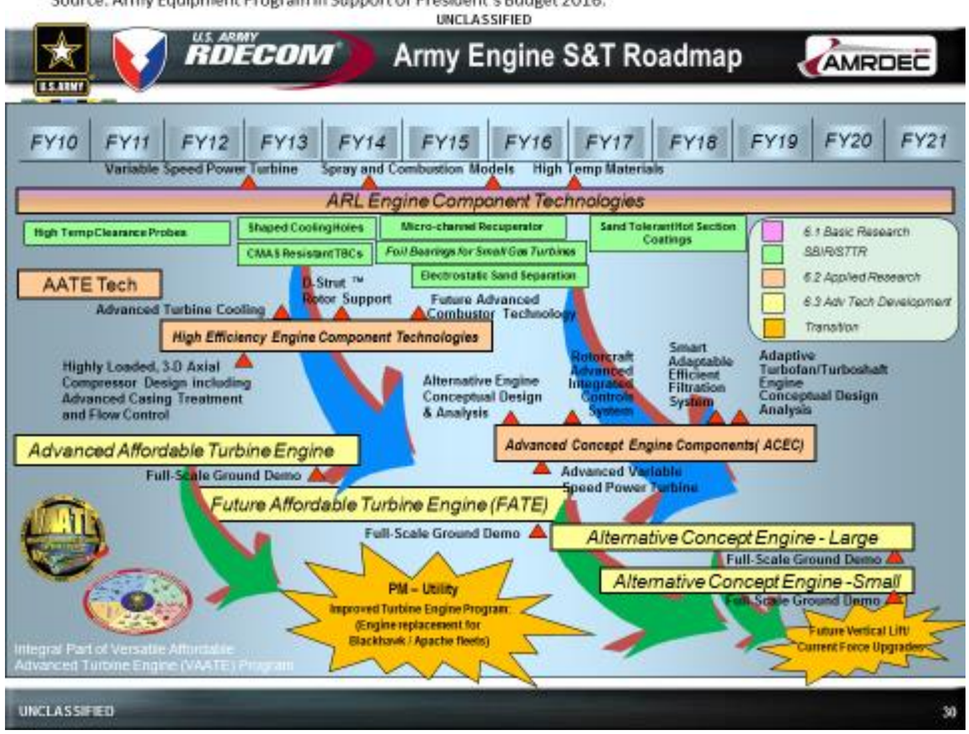
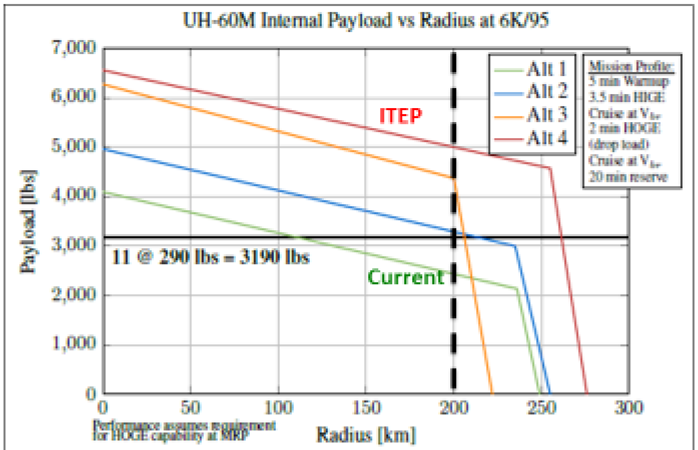


Source: Army Equipment Program in Support of President's Budget 2016.



ITEP Provides Significant Improvement in Performance of Legacy Platforms



Source: ITEP AoA

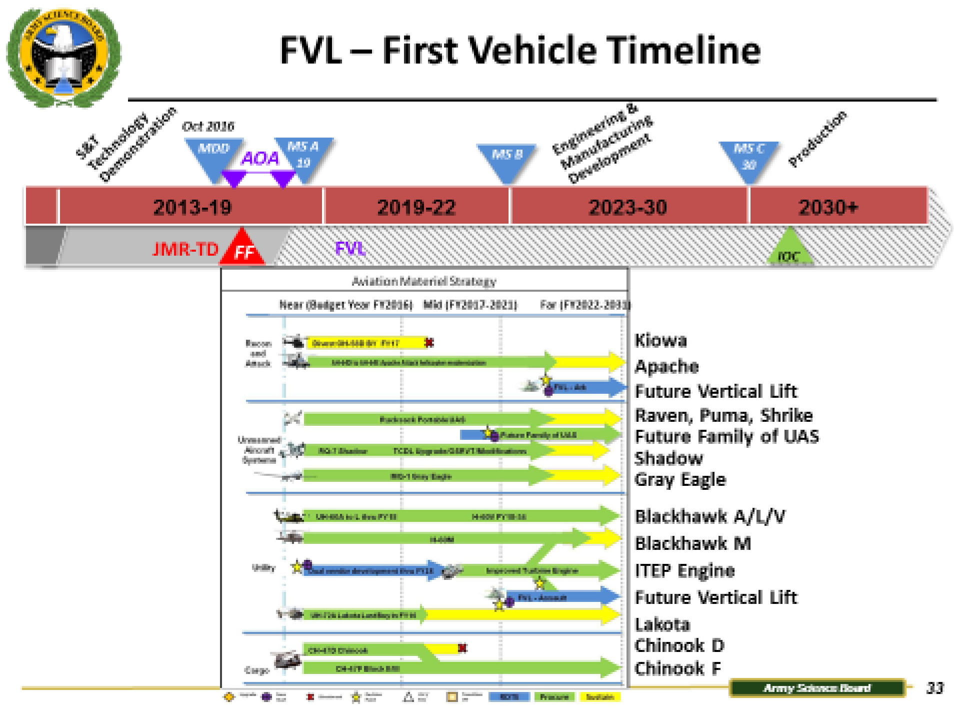
5. FVL Acquisition with Speed and Simplicity

Findings

- JMR-TD and FVL provide focus for Army Aviation S&T for next generation rotorcraft systems and provide a solid basis for much needed capability improvements (Ref. FVL ICD); however, there is no funding for FVL in the POM.
- The JMR-TD vehicles are close in size and aerodynamic performance capability to the FVL medium class system.
- The current FVL schedule leads to an IOC of the first system in the mid 2030s. It should be beneficial to accelerate this timeline through an evolutionary acquisition approach if funding allows.
- The JMR-TD, DARPA X planes, USN/USMC prototyping efforts, and industry investment support talent development and retention in rotorcraft government and industry teams.

Recommendation

- ASA(ALT): Develop an evolutionary acquisition approach for FVL to allow for earliest possible fielding consistent with funding constraints, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).


FVL – First Vehicle Timeline
S&T Technology Demonstration
Oct 2016
MDD
AOA
MS A 19
MS B
Engineering & Manufacturing Development
MS C 30
Production
2013-19
2019-22
2023-30
2030+
JMR-TD
FF
FVL
IOC
Aviation Materiel Strategy
Kiowa
Apache
Future Vertical Lift
Raven, Puma, Shrike
Future Family of UAS
Shadow
Gray Eagle
Blackhawk A/L/V
Blackhawk M
ITEP Engine
Future Vertical Lift
Lakota
Chinook D
Chinook F
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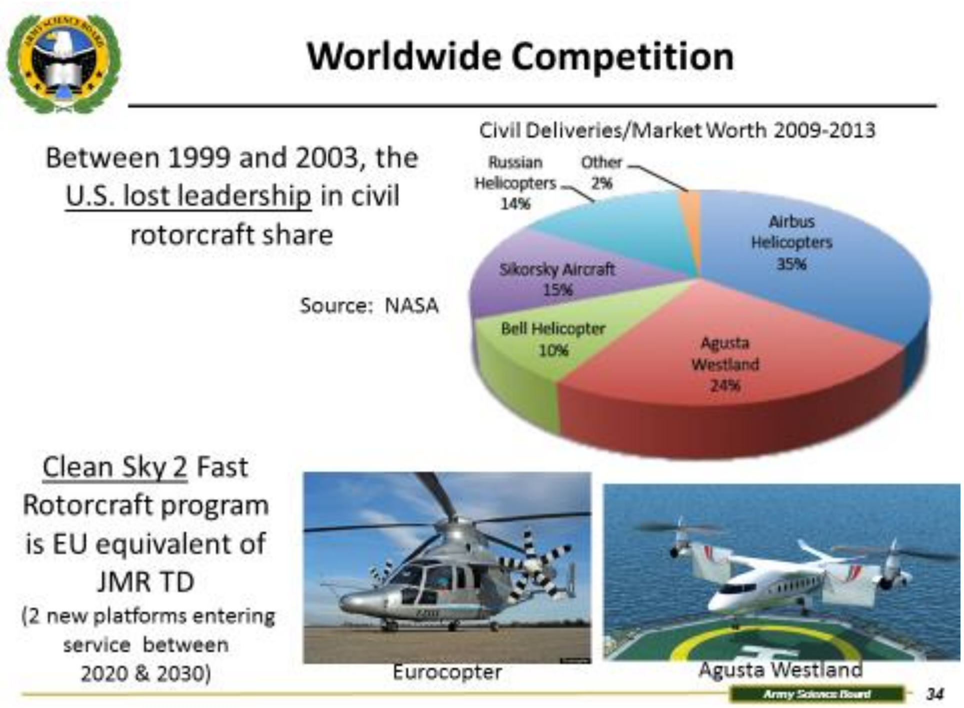
Worldwide Competition
Between 1999 and 2003, the U.S. lost leadership in civil rotorcraft share
Source: NASA
Civil Deliveries/Market Worth 2009-2013
Russian Helicopters 14%
Other 2%
Airbus Helicopters 35%
Sikorsky Aircraft 15%
Bell Helicopter 10%
Agusta Westland 24%
Clean Sky 2 Fast Rotorcraft program is EU equivalent of JMR TD
(2 new platforms entering service between 2020 & 2030)
Eurocopter
Agusta Westland
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6. Aviation Mission Systems

Findings

- Army S&T mission system programs include Lethality, Survivability, Teaming & Autonomy, Human-System Interface, Avionics, and Networks.
- RDECOM DVE goals are appropriate and feasible - Progress at AMRDEC, CERDEC, and ARL in sensors, flight control, cueing, computing, and networking.
- Reduced pilot workload arising from DVE technologies should increase operational mission capacity (e.g., formations with UAS).
- Advanced sensors (e.g., IR, visible, and hyperspectral) are being developed.
- Additional advanced mission systems (e.g., offensive and defensive directed energy) and open system architectures are needed.
- DoD provides singular modeling and wind tunnel capabilities (NASA Ames)

Recommendation

- AMRDEC/ADD: Expand mission system technology development, currently focused on DVE, to enable advanced formation concepts in future manned and unmanned platforms, and legacy platforms as appropriate, as informed by the results of system of systems operational effectiveness analyses (Recommendation 1).

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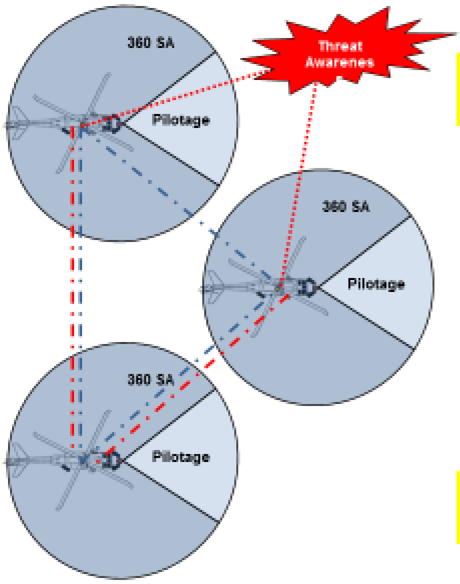
U.S. ARMY RDECOM

DVE-M: Objective Goals



DVE-M PROGRAM – OBJECTIVE DEMONSTRATION GOALS

Threshold Demonstration Goals plus:

- Multi-ship Networking (sharing of data)
- Threat Awareness (hostile fire awareness, targeting, etc.)

DVE-M PROGRAM – OBJECTIVE TECHNICAL GOALS

Threshold Technical Goals plus:

Sensors – Refined fused research configurations for pilotage including:

- Threat awareness (currently limited to a paper study cross-walk)

Flight Controls – Partial autonomous capability:

- MCLAWS v6
- Aircraft state data (partial autonomy & cueing feed)

Cueing – Best of breed for takeoff, enroute, & landing

- Symbology
- Tactile
- Aural

Complex Computing – Optimized latency for pilotage including

- Multi-ship networking (limited capability)

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7. Aviation Systems Integration and Testbed

Findings

- Concepts developed in Recommendation 1 and new technical capabilities referenced in Sections 2-6 (individually and as integrated systems) will require extensive testing.
- Some initial work is found in CERDEC I2WD open systems efforts and DARPA's System of Systems Integration, Technology and Experimentation (SoSITE).
- Fully integrated joint vision for aviation in DoD is not evident. Coalition environment should be considered.

Recommendations

- RDECOM: Build the components of an integrated "survivable" system (MUM-T, attritable assets, secure comm, PNT, open operating systems, autonomy, high/low mix, distributed functions across future "formations").
- RDECOM: Building on Recommendation 1 and Sections 2-6, develop an aviation integration testbed for experimentation and validation of technology, prototypes, and concepts. Potentially include demonstration (such as JMR TD), prototype, surrogate, and operational systems.

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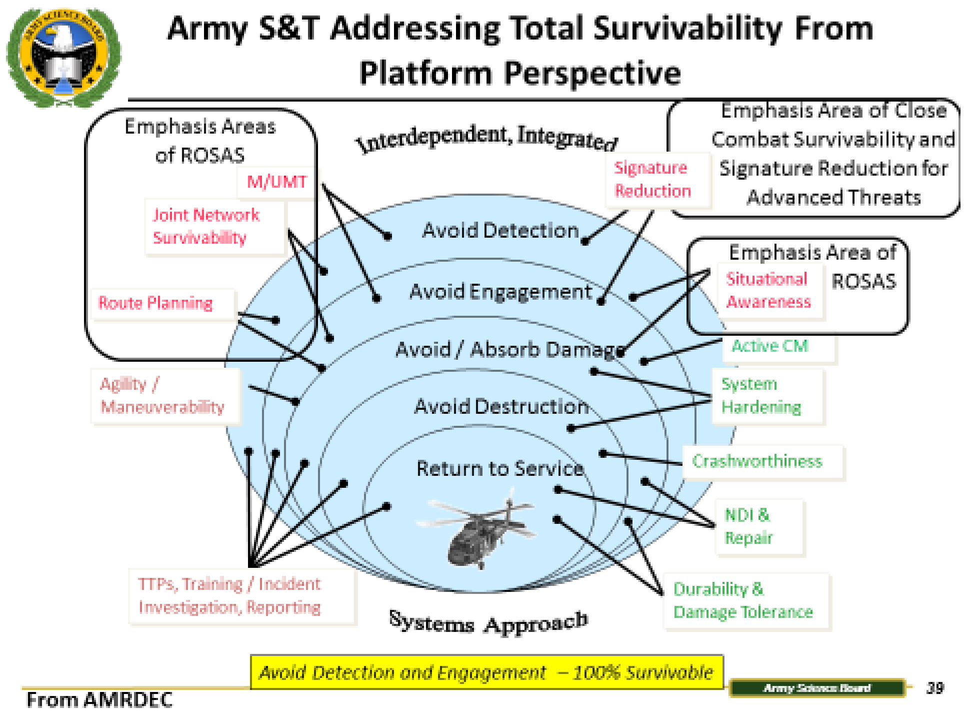
Army S&T Addressing Total Survivability From
Platform Perspective
Emphasis Areas
of ROSAS
M/UMT
Joint Network
Survivability
Route Planning
Agility /
Maneuverability
TTPs, Training / Incident
Investigation, Reporting
Interdependent, Integrated
Signature
Reduction
Emphasis Area of Close
Combat Survivability and
Signature Reduction for
Advanced Threats
Emphasis Area of
Situational
Awareness
ROSAS
Active CM
System
Hardening
Crashworthiness
NDI &
Repair
Durability &
Damage Tolerance
Avoid Detection
Avoid Engagement
Avoid / Absorb Damage
Avoid Destruction
Return to Service
Systems Approach
Avoid Detection and Engagement – 100% Survivable
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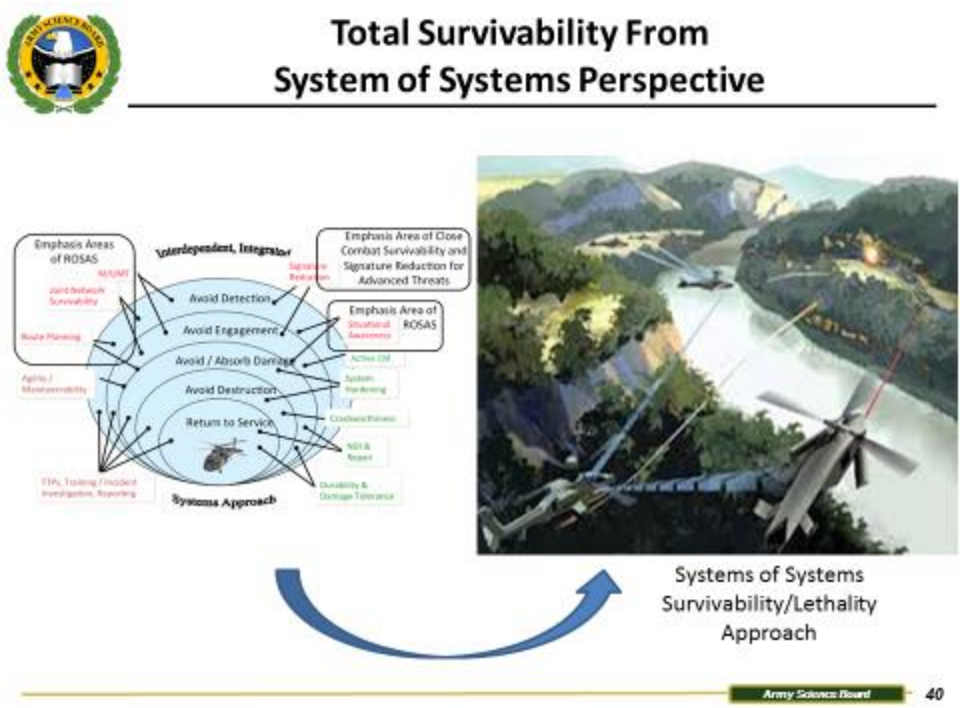
From AMRDEC


Total Survivability From
System of Systems Perspective
Systems of Systems
Survivability/Lethality
Approach
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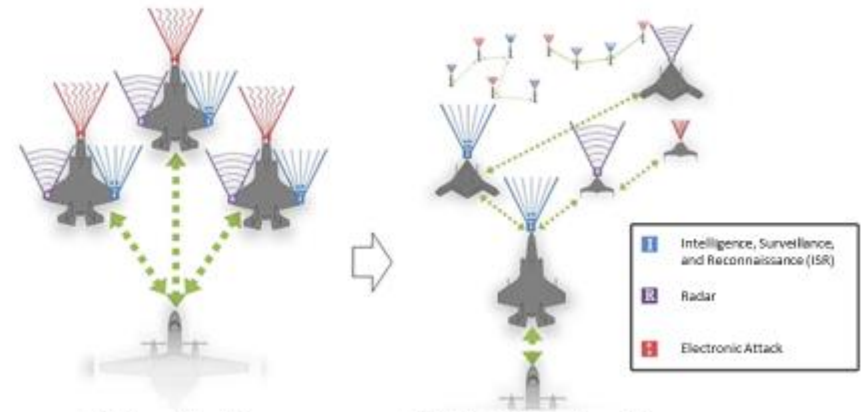
SoSITE System of Systems Example



Platform Centric
Vulnerable to countermeasures

Distributed Functionality
Robust to countermeasures

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Source: DARPA SoSITE website

Findings & Recommendations Overview

<u>Context: Character of Warfare in 2025 and Role of Army Aviation</u>

1. System of Systems Operational Effectiveness Analyses
2. Affordability of Heavy Vertical Lift

<u>Addressing Capability Gaps: Development and Acquisition</u>

3. UAS Vehicles
4. Modernization of Legacy Rotorcraft Systems
5. FVL Acquisition with Speed and Simplicity
6. Aviation Mission Systems
7. Aviation Systems Integration and Testbed

<u>S&T Portfolio: Innovation and Game Changers</u>

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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8. Advanced and Disruptive Systems S&T

Findings

- Army aviation is at a crossroad of challenge and opportunity.
  - The challenge: threat sophistication will demand a transformation in the nature of warfare in 2025 and beyond (missiles, UAS, DE, Cyber).
  - The opportunity: technology is emerging that enables significant improvement in aviation capabilities.
- Advanced technology solutions are required, including: UAS, autonomy, manned-unmanned collaboration, communications, directed energy, sensors, condition-based and near-zero maintenance technology/concepts, and other discoveries from the S&T enterprise.
- There is relevant work in other Services, DARPA, and NASA that should be leveraged.

Recommendations

- RDECOM: To address expanding complex threats and opportunities develop advanced technologies for an integrated/holistic, manned/unmanned architecture/system to ensure survivability and mission success.
- ASA(ALT): Include in S&T portfolio leap-ahead technologies (counter-DE, counter-UAS, advanced materials)

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Aviation Innovation Examples

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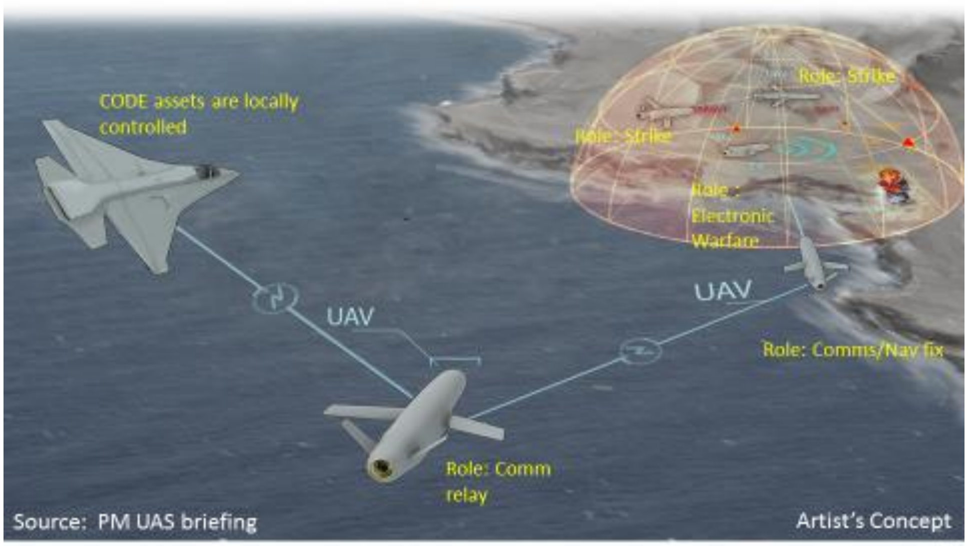
Collaborative Operations in Denied Environment (CODE)



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9. S&T Investment

Findings

- Based on findings in Sections 1-8, the capabilities of Army Aviation S&T must evolve rapidly (e.g., need to expand UAS and autonomy activity); thus the level of S&T activity must expand beyond the manned aviation S&T portfolio, which is currently well managed.
- Army S&T investment has led to successful ITEP and FATE engine developments; the transition of these S&T efforts to PORs is essential to both FVL and modernized legacy platforms.
- Current S&T investment is insufficient to achieve the needed transformation and to maintain overmatch in 2025 and beyond.

Recommendations

- AMRDEC/ADD: Continue active participation in VAATE and RAMPED engine development.
- RDECOM: Explore innovative mechanisms for external collaboration (university, industry, etc.), such as grand challenges (similar to DARPA construct).
- ASA(ALT): After exploring leveraging opportunities with other R&D activities, advocate more funding for Aviation S&T.

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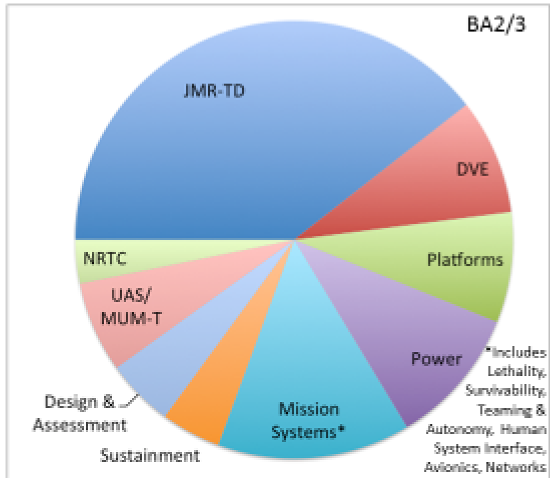
Meeting Future Challenges Demands a Robust Aviation Portfolio

- Army FY16 Requested TOA is $126B
- Procurement Total is $16.1B
- Aviation Procurement is $5.7B (34% of Procurement)
- Army S&T* Total is $1.77B
- <u>Army Aviation S&T* is $144M</u> (8% of S&T)
- DoD Rotorcraft S&T* is $207M (Army is lead Service with 64% of total)
- NASA Rotorcraft Funding is $20M

*BA2/3



Current level and focus of funding is inadequate to meet challenges

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Findings & Recommendations Summary

<u>Context: Character of Warfare in 2025 and Role of Army Aviation</u>

1. System of Systems Operational Effectiveness Analyses
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<u>S&T Portfolio: Innovation and Game Changers</u>

8. Advanced and Disruptive Systems S&T
9. S&T Investment Strategy

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Future of Army Aviation

Threats are rapidly changing

- Character of warfare is changing
  - Army aviation must change too

Need new **concepts** - beyond stand-alone platforms

- New joint battlespace system-of-systems architecture/CONOPS
  - New systems – UAS, FVL, autonomy, missions systems
    - New prototyping, experimentation, and testbed

Increase **innovation** and risk-taking to leap ahead/anticipate

Survive and Win as an Aviation System of Systems

APPENDIX K ABBREVIATIONS AND ACRONYMS

A2	Anti-Access
AATD	Aviation Applied Technological Directorate – merged with AFDD to form ADD – Ft Eustis, VA
ACAT I	Acquisition Category I (Major Defense Acquisition Programs)
AD	Area Denial
ADD	Aviation Development Directorate in AMRDEC – Merger of AATD and AFDD
AFDD	Aeroflight Dynamics Directorate – merged with AATD to form ADD – Moffett Field, CA
AFOSR	Air Force Office of Scientific Research – Arlington, VA (see also ARO and ONR)
AFRL	Air Force Research Laboratory (see also ARL and NRL)
AH	Attack Helicopter
AIPT	Acquisition IPT (FVL – Army PEO Aviation lead)
AMCOM	Aviation and Missile Command
AMRDEC	Aviation and Missile RDEC – Redstone Arsenal, Huntsville, AL
AO	Area of Operations
AoA	Analysis of Alternatives
APG	Aberdeen Proving Ground, MD
ARCIC	Army Capabilities Integration Center – subordinate to TRADOC
ARDEC	Armament RDEC – Picatinny Arsenal, NJ
ARES	Aerial Reconfigurable Embedded System (DARPA effort)
ARI	Aviation Restructuring Initiative proposed by Army
ARL	Army Research Laboratory – Adelphi, MD and APG, MD (see also AFRL and NRL)
ARO	Army Research Office, part of ARL – Raleigh-Durham, NC – Oversees external efforts in BA1 (see also AFOSR and ONR)
AS	Aviation Systems – a PM in PEO Aviation
ASA(ALT)	Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
ASB	Army Science Board
ASD(R&E)	Assistant Secretary of Defense (Research & Engineering)
ASE	Aircraft Survivability Equipment
ASH	Armed Scout Helicopter – a PM in PEO Aviation
ASSP	Aviation S&T Strategic Plan (produced by ADD)
ASW	Anti-submarine Warfare
AUSA	Association of the US Army
BA1	Budget Activity 1 (DoD), Basic Research - directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. Also called 6.1
BA2	Budget Activity 2 (DoD), Applied Research - systematic expansion and application of knowledge to develop useful materials, devices, and systems or methods. Also called 6.2
BA3	Budget Activity 3 (DoD), Advanced Technology Development (ATD) - development of subsystems and components and efforts to integrate subsystems and components

	into system prototypes for field experiments and/or tests in a simulated environment. Also called 6.3
BA4	Budget Activity 4 (DoD): Demonstration and Validation - Dem/Val includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
BA5	Budget Activity 5 (DoD): Engineering and Manufacturing Development - EMD includes those projects in engineering and manufacturing development for Service use but which have not received approval for full-rate production..
BA6	Budget Activity 6 (DoD): RDT&E Management Support - Includes R&D effort directed toward support of installations or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, O&M of test aircraft and ships, and studies and analyses in support of the R&D program.
BA7	Budget Activity 7 (DoD): Operational Systems Development. - Includes those development projects in support of development acquisition programs or upgrades still in EMD, but which have received Defense Acquisition Board (DAB) or other approval for production, or production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.
BDA	Battle Damage Assessment
BRAC	Base Realignment and Closure
C2	Command and Control
C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
CAPE	Cost Assessment and Program Evaluation (OSD)
CAS	Close Air Support
CBA	Cost-Benefit Analysis or Capabilities Based Assessment (part of JCIDs process)
CBM	Condition Based Maintenance
CCA	Close Combat Attack
CCS	Close Combat Survivability
CERDEC	Communications-Electronics RDEC – APG, MD
CG	Commanding General
CH	Cargo Helicopter
CIPT	Commonality IPT (FVL – Navy PEO Assault and ASW lead)
CM	Countermeasure
CODE	Collaborative Operations in Denied Environment (DARPA effort)
COE	Center of Excellence
COI	Community of Interest
CONOP	Concept of Operations
CONUS	Continental US
CSA	Chief of Staff of the Army
CSAR	Combat Search and Rescue
DA	Direct Attack
DAB	Defense Acquisition Board

DARPA	Defense Advanced Research Projects Agency
DE	Directed Energy (includes high energy laser and high powered microwave)
DHS	Department of Homeland Security
DoD	Department of Defense
DSB	Defense Science Board
DTIC	Defense Technical Information Center (www.dtic.mil)
DVE	Degraded Visual Environment (includes brownouts, whiteouts, rain, snow, fog, sleet, mist, etc.)
DVE-M	DVE - Mitigation
ECBC	Edgewood Chemical and Biological Center – Edgewood, MD
EMD	Engineering and Manufacturing Development
EMI	Electromagnetic Interference
EO	Electro-Optic
ESD	Electrostatic Discharge
EW	Electronic Warfare
FA	Focus Area (at ADD)
FACE	Future Airborne Capability Environment
FATE	Future Affordable Turbine Engine
FCS	Future Combat System
FoS	Family of Systems
FOUO	For Official Use Only
FVL	Future Vertical Lift
FW	Fixed Wing – a PM in PEO Aviation
FY	Fiscal Year
GCS	Ground Control System
GMTI	Ground Moving Target Indicator
GPS	Global Positioning System
HA/DR	Human Assistance/Disaster Relief
HOGE	Hover Out of Ground Effect
HQDA	Headquarters Department of the Army
HSL	Helicopter Sling Load
HUMS	Health and Usage Monitoring System
HVL	Heavy Vertical Lift
I2WD	Intelligence and Information Warfare Directorate of CERDEC – APG, MD
ICD	Initial Capabilities Document
IED	Improvised Explosive Device
IEW&S	Intelligence, Electronic Warfare & Sensors
IHSMS	Integrated Hybrid Structures Management System (Navy)
ILIR	In-House Laboratory Innovative Research (BA1)
IOC	Initial Operational Capability
IPT	Integrated Product Team
IR	Infrared
ISR	Intelligence, Surveillance, and Reconnaissance
ITEP	Improved Turbine Engine Program

IVSHM Integrated Vehicle Self Health Monitoring
JAGM Joint Air-to-Ground Missile
JCA Joint Common Architecture
JCIDS Joint Capabilities Integration and Development System, the formal United States DoD procedure that defines acquisition requirements and evaluation criteria for future defense programs
JF Joint Force
JFTL Joint Future Theater Lift – concept to lift 20-36 tons – USAF lead JFTL definition 2008-2012, canceled 2012
JFVL Joint Future Vertical Lift
JHL joint Heavy Lift – Army exploration of large tilt-rotor concept to lift ~30 tons over theater distances
JLTV Joint Light Tactical Vehicle
JMR Joint Multi-Role
JROC Joint Requirements Oversight Council
kt knot (1 nautical mile per hour = 1.852 km per hour)
LCC Life Cycle Cost
LGB Laser-Guided Bomb
LIRA Long-Range Investment Requirements Analysis
M&S Modeling & Simulation
MANPADS Man-Portable Air Defense System
MCLAWS Modernized Control Laws
MDD Materiel Development Decision
MEDEVAC Medical Evacuation
MEP Mission Equipment Package
MFOP Maintenance Free Operating Period
MSA Milestone A – decision to move from Materiel Solution Analysis to Technology Development
MSB Milestone B – decision to move from Technology Development to Engineering and Manufacturing Development
MSC Milestone C – decision to move from Engineering and Manufacturing Development to Production and Deployment
MUM-T Manned Unmanned Teaming
NASA National Aeronautics and Space Administration
NAVAIR Naval Air Systems Command
NDI Non-Developmental Item
NDIA National Defense Industrial Association
NEO Noncombatant Evacuation Operations
NM Nautical mile
NRL Naval Research Laboratory – Washington, DC (see also AFRL and ARL)
NRTC National Rotorcraft Technology Center at NASA Ames – an interagency team of NASA, Army, Navy, and FAA – focuses government, industry, and academic resources
NSRDEC Natick Soldier RDEC - Natick MA

NSRWA	Non-Standard Rotary Wing Aircraft – a PM in PEO Aviation
NVESD	Night Vision and Electronic Sensor Directorate of CERDEC – Ft. Belvoir, VA
O&M	Operations and Maintenance
O&S	Operations and Support
OCO	Overseas Contingency Operations
OEF	Operation Enduring Freedom
OMS	Open Mission Systems (USAF effort)
ONR	Office of Naval Research – Arlington, VA (see also AFOSR and ARO)
OSA	Open Systems Architecture
OSD	Office of the Secretary of Defense
OT&E	Operational Test and Evaluation
P3I	Pre-Planned Product Improvement
Pax	Passengers
PEO	Program Executive Office, e.g. PEO-Aviation at Redstone Arsenal, AL
PHM	Prognostic Health Management
PM	Program Manager in PEO, e.g., in PEO Aviation PMs are Apache, AS, ASH, Cargo, NSRWA, UH, UAS, FW
PNT	Positioning, Navigation and Timing
POD	Point of Departure or Point of Debarkation
POM	Program Objective Memorandum
POR	Program of Record – Acquisition program that has achieved MSB
R&D	Research and Development
RDA	Research Development and Acquisition
RDEC	Research, Development, and Engineering Center
RDECOM	Research, Development, and Engineering Command – RDECOM Organizations include ARDEC, AMRDEC, CERDEC, ECBC, NSRDEC, TARDEC and ARL – APG, MD
RDTE	Research Development Test & Evaluation (RDT&E funding includes BA1-BA7 budget areas)
RF	Radio Frequency
RIPT	Requirements IPT (FVL – TCM-Lift lead))
ROSAS	Route Optimization for Survivability Against Sensors (Army effort)
RSOI	Reception, Staging, Onward movement, and Integration
RSTA	Reconnaissance, Surveillance, and Target Acquisition
RVLT	Revolutionary Vertical Lift Technology (NASA project)
RW	Rotary Wing – a PM in PEO Aviation
S&T	Science & Technology – within DoD funded by BA1, BA2, and BA3
SA	Situational Awareness
SAM	Surface to Air Missile
SAR	Synthetic Aperture Radar
SBIR	Small Business Innovative Research
SEAD	Suppression of Enemy Air Defense
SIGINT	Signals Intelligence
SIL	Software Integration Laboratory
SLAD	Survivability/Lethality Analysis Directorate (ARL)

SOCOM	Special Operations Command
SOF	Special Operations Force
SOIPT	S&T Overarching IPT (FVL – AMRDEC lead)
SoS	System of Systems
SoSITE	System of Systems Integration technology and Experimentation (DARPA effort)
SRAT	Signature Reduction Against Threats
STOL	Short Take-Off and Landing
SuW	Surface Warfare (Navy)
SWAP	Size, Weight, and Power
TA	Technical Area (at ADD)
TARDEC	Tank Automotive RDEC – Warren, MI
TCM	TRADOC Capability Manager
TD	Technology Demonstration
TOA	Total Obligation Authority
TOR	Terms of Reference
TRADOC	US Army Training and Doctrine Command – Ft Eustis, VA
TTO	Tactical Technology Office (DARPA)
TTP	Tactics, Techniques, and Procedures
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UH	Utility Helicopter – a PM in PEO Aviation
UNK	Unknown
UQ	Unified Quest (Army chief of staff annual future studies program, includes wargame)
USA	US Army
USAACE	US Army Aviation Center of Excellence – Ft. Rucker, AL
USAARL	US Army Aeromedical Research Laboratory – Ft. Rucker, AL
USAF	US Air Force
USCG	US Coast Guard
USMA	US Military Academy at West Point
USMC	US Marine Corps
USN	US Navy
V/STOL	Vertical/Short Take-Off and Landing
VAATE	Versatile Affordable Advanced Turbine Engine
VCSA	Vice Chief of Staff of the Army
VLC	Vertical Lift Consortium (Industry)
VLRCOE	Vertical Lift Research Center of Excellence (at Georgia Tech, Penn State, and U Md) – Funded with BA1
VRAMS	Virtual Risk-informed Agile Maneuver Sustainment
VTOL	Vertical Take-Off and Landing
WIPT	Working IPT under SOIPT (FVL)
WMD	Weapons of Mass Destruction
ZMA	Zero Maintenance Aircraft

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